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LECTURES

LIGHT AND TEMPORARY RAILWAYS,

AND

TEMPORARY EXPEDIENTS

IN

ENGINEERING CONSTRUCTION.

DELIVERED AT THE

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Two Lectures delivered in the Spring of 1880, together with extracts from a previous Lecture, now out of print, delivered at the School of Military Engineering, Chatham, in 1873, are here bound up together, as they all bear upon a class of temporary work which the Military Engineer may at any time be called upon to perform, and it was deemed advisable to make the subject as complete as possible.

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LIGHT AND TEMPORARY RAILWAYS.

BY

CHARLES DOUGLAS FOX, Esq., M.I.C.E.

SPRING SESSION, 1880.

Light railways.

OUR subject naturally divides itself into two parts. To deal even generally with "Light Railways" will fully occupy our time this evening, and the very interesting subject of "Temporary Railways" will thus form the basis for a second lecture, if it should be desired.

The title originally suggested was that of "Narrow Gauge Railways," but it will presently be seen that, after all, the gauge, or distance between the rails, although an important, is not the chief factor in the design of economical railways, and the present title was therefore substituted.

By the term "Light Railways," the author would wish to be understood such as, being either branches from existing trunk lines, or being intended for districts requiring the development of their traffic, are constructed in a thoroughly substantial and durable manner, but with every part made only of such strength as to carry lighter loads, and these at lower speeds, than on heavier railways.

Loads provided for.

Upon the railways about to be described, the rolling loads provided for were represented by a maximum of six tons per axle or three tons per wheel, with a maximum speed of 20 miles per hour, exclusive of stoppages.

Gauge adapted.

It so happens that these railways are all either of the 3′ 6″, the mêtre, or the 3′ gauge, but the principles of their construction may be equally well applied to the 4′ 8½″, or other gauges.

Gauges discussed.

The standard gauge of English Railways, viz: 4′ 8½″ was not determined upon any scientific principles, but grew out of the adoption—before railways were thought of—of first, stone, and then iron tram-plates, upon which ordinary road-wagons ran, and which were laid to this gauge as suiting the general width between the waggon wheels. Thus, when railways were commenced this gauge became general, and, when Brunel proposed the adoption of a 7′ gauge, with the idea of introducing still higher speeds and greater stability, a fierce battle of gauges arose, which has since that time, in spite of the costly experience of the Great Western Railway Company, been fought over again in different parts of the world, and notably of late years in connection with Canadian and Indian Railways. In almost all these cases, however, the controversy has been complicated by the question of Break of Gauge, and the undoubted evils

Gauges discussed.

consequent thereon, both from a military and from a commercial point of view. It will probably be generally admitted that, where railways are to be made use of for the rapid and regular transport of men and munitions of war, the gauge, be it broad or narrow, should undoubtedly be uninterrupted, so that transhipment, with its attendant delays and confusion, may be avoided; and that trains may run through from the centres of supply to the frontiers or scenes of action with regularity and ease, and so that the rolling stock and locomotives of a whole country may, when required, be concentrated.

Even where the military question does not arise, a strong tendency to uniformity of gauge is being manifested amongst practical men; for example, in Canada the extensive system of 5′ 6″ gauge railways has been already narrowed to the standard gauge of 4′ 8½″, whilst the Companies having lines of the 3′ 6″ gauge are intending, as soon as they can afford the expense, to widen their lines up to the same standard. It is to be regretted that in India, and to some extent in England, break of gauge is being again permitted. It would probably have been better to gradually narrow the trunk lines in India, at present 5′ 6″ gauge, to some more moderate gauge, say 4′ 8½″, or even down to 4′, so arranging the standard that it should not be the same as in Russia, than to have, as at present, two systems of railways interlacing with one another, but of different gauge.

As to the most suitable gauge for the purposes of general traffic, the accumulated experience of Great Britain, the greater part of Europe, and of the United States, points to 4′ 8½″, or thereabouts, as offering most advantages. The broader gauges adopted on some lines in these countries are, as before mentioned, gradually disappearing, being found to yield no such improved results in cost of working and speed as were claimed by their advocates, or as could counterbalance the increased first cost, and the constant grievance of break of gauge.

When gauges narrower than 4′ 8½″ were first introduced, great prospective economy of first cost was claimed, but experience has proved that comparatively little saving results from the actual width between the rails, or the gauge being narrowed; but that the cost depends far more upon other matters, such as:—

1st. The rolling loads to be carried.
2nd. The speed of the trains to be provided for.
3rd. The width of the rolling stock.

In many cases unfair comparisions have been made between a main line 5′ 6″ gauge, with 70lb. rails suitable for rolling loads of 8 tons per wheel, and speeds of 40 miles per hour, and a 3′ gauge railway with 40lb. rails, and suitable for rolling loads of three-and-a-half to four tons per wheel, and speeds of 20 miles per hour. In such instances a careful analysis would prove that not the gauge, but the complete modification and reduction of all details brought about the chief part of the saving in first cost. Break of gauge has thus, on more than one occasion, been deliberately submitted to, in order to be free from the restrictions upon economy, resulting from an uniform gauge.

Where, however, the proposed railway is isolated, and the gauge question can be considered upon its merits, apart from break of gauge, and where economy is of importance, there is no practical objection to reducing the gauge to 3′, or 3′ 3⅜″. For the few short lines which have

Gauges discussed.

been constructed of still narrower dimensions special expedients have to be introduced for dealing with the fireboxes of the locomotives, and with the rolling stock, and it is open to much question whether any corresponding benefit is derived from these minute dimensions,—at any rate for a railway which, though light, is intended to be permanent.

The first light railway system of any importance was that of Norway, where Mr. Carl Pihl, as long ago as 1856, introduced the 3′ 6″ gauge, combined with light rolling loads, slow speeds, and rails weighing 40lbs. to the yard, (a main line rail in England weighs often 84lbs. to the yard). Soon afterwards a light railway on the 3′ 6″ gauge was constructed in India. Since that time this gauge has been adopted very largely in Australia, New Zealand, the Cape of Good Hope, Canada and elsewhere, whilst the mêtre, or 3′ 3⅜″ gauge, has spread very extensively in India and South America, and some very lengthy lines have been constructed in the United States upon the 3′ and 2′ 9″ gauges.

Laying out railroads.

The first step in the construction of any railway—its laying out, or location—is one which is but too often committed to inexperienced hands, and hurried over to the lasting detriment of the work. Nothing requires more skill and practice on the part of the Engineer, and this very specially in the case of light railways, where advantage can more readily be taken of the natural features of the country, than is the case with heavier lines, where steep gradients and sharp curves are not admissible. Noting carefully the places to be served, the Engineer first rides or walks over the whole route, making notes of the character of the country, the geological features, the watersheds, the timber, stone, and other materials to be found within easy access, and the character and quantity of labour available. In most cases abroad no reliable maps are to be had, so that the compass must be put under requisition, and with this, a pocket-sextant, and an aneroid barometer, an experienced Engineer can, in ordinary country, so approximate to the best route, as to avoid much subsequent labour. This being done, one or more trial sections are taken, where there is any doubt as to the best centre line, together with frequent cross-sections, which enable the Engineer to adjust the centre line in the office. The object is, of course, to lay out the railway as nearly straight and level as considerations of economy will permit, but as this can only partially be effected, even under the most favourable circumstances, maximum, or ruling gradients, and minimum curves are first decided upon. Unless the country is very difficult, only such gradients and curves are permitted as can be dealt with without introducing unusual or exceptional mechanical expedients. A very common limit on light railways has been a maximum gradient of 1 in 40 and of moderate unbroken length, and a minimum radius for curves of 330 feet. A serious loss of power results, as is well known, from the use of gradients and curves, especially when in combination, and to balance this loss of power in the locomotives, a constant evil, against higher cost of construction in the first instance, is a matter of close calculation in each case. Curves are avoided as much as possible on gradients, and upon long inclines short portions of level are inserted. Short lengths of steep gradients, and sharp curves can be introduced with comparatively little effect upon the speed and weight of trains, and often difficulties can thus be surmounted, without excessive cost. Experience has shown that in many instances, and especially in constructing cheap narrow gauge railways, gradients and curves have been introduced to such an extent, as

Laying out railroads.

to most seriously impair the efficiency of the line for purposes of traffic, and in some cases, heavy expenses have been afterwards incurred, in removing these defects.

The question of earthworks, of course, greatly affects the laying out of the line, and this differently in different countries. Usually it is desirable in a rolling or undulating country, such as Great Britain, and where land is valuable, to balance or equalize the cuttings or embankments, so that the latter may (where the lead is not too long) be made from the former, avoiding side cuttings and spoil banks. If, in addition, the lead can be arranged to be down hill, the expense is greatly reduced. In India, however, embankments are more cheaply made from side ditches by basket work. In America large flat ploughs or scrapers, drawn by horses, are used for the same purpose. In Canada, and other countries exposed to snow drifts, cuttings are avoided as much as possible, as they are the source of much expense in keeping the line open in winter. The level of the rails is therefore kept high, and the valleys, being in the first instance crossed by wooden trestles, are within a few years filled in from side cuttings. The trestles are generally made of fir trees, cut down and used with as little labour upon them as possible. In Canada, too, care is taken not to cross the lines of heavy snow drifts, where it can be avoided. Comparatively little saving is effected in this item by reduction of gauge.

Before fixing the centre line, the sites of all important bridges are examined as, by a lateral deviation, the foundations may often be greatly modified and the general expense of the bridge reduced.

The centre line having been decided upon, is then carefully set out by chain and theodolite, or pocket sextant, strong pegs being driven in at intervals, and specially at the tangent points of curves, and at the angle of intersection of the tangent, and the working plan and section are prepared.

Where the line passes through growing timber, this is cleared for a width of 66 feet, and for such further width in special cases, as is necessary to prevent trees falling across the line, and to protect the line to some extent from forest fires. In cuttings and embankments of less than 5 feet, the roots of the trees are grubbed up,—in the higher embankments they are left. Where the formation level is practically on the surface, the ground is trimmed off for the reception of the ballast.

Fencing.

Fencing is a luxury which is, to a considerable extent, dispensed with in thinly-populated countries; but an insufficiently fenced railway is a source of constant trouble and danger, and a continuous fence on each side has been generally adopted on the railway under description. In wooded countries the whole trees cut down for clearing are, without much labour upon them, used as a snake fence, which, although rough and heavy looking, is very effective. In hot climates the cactus and prickly pear give good protection. Where timber is costly, a fence can be rapidly constructed of four galvanized wire stands, each composed of seven galvanized wires 15 B.W.G., fixed at every three yards to iron or wooden intermediates, by galvanized staples, and strained at every 220 yards by screws or ratchets. This wire can be carried on reels, like field telegraph wire, and led out along the railway by a horse. Gates are frequently dispensed with, level crossings being protected by American

Cattle guards.

Cattle Guards, which consist of a rectangular pit, enclosed by timber or brickwork, and running across the whole width of the railway, about 12

Cattle loads.

feet wide and four feet deep, the rails being carried across by baulks of timber too narrow for animals to walk on. The well known wedge-shaped projection on the locomotive, called a cow-catcher, also acts very effectually in removing from the track any animal which may stray upon it. Thus the constant expense of level crossings is reduced to a minimum. In Canada, fences of close boardings are used in positions exposed to snow-drifts, arranged at such an angle as to catch the drift, and divert it from the line.

Formation level and slopes.

The formation level, on the bottom of cuttings and the top of embankments, ready to receive the ballast, is made considerably narrower than on heavier railways. In India, where exposed to heavy rains, the width is 14 feet on the embankments, but generally the dimensions are 12 feet wide on embankments and 14 feet wide in cuttings, the gauge being from 3′ to 3′ 6″, the usual English width on the 4′ 8½″ gauge being 17 and 19 feet respectively. The slopes are, of course, not dependent upon gauge, but upon the nature of the materials, and are usually as follows:—

	Cuttings.	Banks.
In clay or wet sand	2 — 1	2 — 1
In gravel or dry sand	1 — 1	1½ — 1
In chalk	¼ — 1	1 — 1

In order to diminish the width of land as much as possible, the cess, or berm, outside the slopes is generally reduced to six feet, and sometimes even to three feet.

The expense of soiling, and afterwards sowing, the slopes is generally dispensed with, although an admirable precaution where cost is not so serious a matter.

The formation level is carefully rounded off from centre to sides, to prevent the lodgement of water, and drains are cut at the bottom of the slopes on each side of cuttings which, on the better constructed lines, are supplied with drain tiles, and then filled with broken stone or gravel.

Effective drainage must be secured at any cost, or maintenance can never be kept up at a moderate rate. Where the ground is very wet, cross drains are laid at every chain across the formation level.

Telegraph.

So soon as the line is cleared, a line of telegraph is fixed, for both temporary and permanent use, thus enabling the Engineer at head-quarters to direct his staff, and greatly reducing the delays in carrying out instructions.

Tunnels.

As a rule, tunnels have been avoided on the lines under description, and where adopted, in one instance, have only differed from those on other lines in having the reduced width of 12 feet.

Openings for flood-water, &c.

The question of waterway is one of the most serious that arises in connection with these railways. Bridges for roads are avoided by the substitution of level crossings, and these without even gates, but floods cannot be dealt with thus, and the bridges and culverts requisite to carry off the storm waters, form, in some instances, a most serious item of cost, and therefore demand most careful study on the part of the engineer, before they are determined upon. Thus, on the South Indian Railway, upon the 3′ 3⅜″ gauge, out of a total cost of £6,500 per mile, bridges and culverts rank for nearly £1,500 per mile. The culverts are constructed

Opening for flood-water, &c.

of various materials. In some cases, in peat or other very soft soil likely to yield under a passing train, timber trunks, formed of planks grooved and tongued, bound together by straps and well tarred, are adopted; in other cases brick or stone abutments with timber tops. In India, where it is important to keep the rails as near to the surface of the ground as possible, and yet to provide headway for floods, the openings down to even six feet, are covered with iron beams, so arranged as to carry the load as directly as possible. In larger spans, built girders are substituted for rolled beams, and in order to save height, cross-girders carry the rails. This mode of construction, however, is much more costly than where the rails run on the top of the main girders, and this latter plan is followed wherever practicable. Thus for a span of 70 feet, the weight of a bridge having the rails on the top is 12 tons, whilst for the same span with the rails between the girders the weight is 21 tons. Very little economy can with safety be exercised in designing the foundations of bridges, for, be the gauge broad or narrow, the rolling loads heavy or light, the forces of scour and frost are the same, and thus, even on light railways, it is usual to put in substantial masonry, piers, and abutments for all important bridges, as any failure in these must involve such serious delay to the traffic, and also heavy expenditure before it can be made good. Great care is required, where foundations are exposed to scour, in determining the depth to which they should be carried. Many of the bridges in India cross rivers with deep sandy beds, and these rivers often (being uncontrolled) completely change their course in a year or two, thus offering a most perplexing problem to the Engineer. The plan applied on the South Indian Railway (a mêtre gauge line), has been to sink the piers and abutments through the sand down to the rock, even where this is 60 feet below the bed. In carrying this out, a modification of the native plan of well-sinking is adopted. An iron curb 12 feet in diameter is prepared, upon which a brick well is gradually built, the sand being pumped out by centrifugal pumps, and the well weighted with rails until the curb reaches the rock. The interior is then filled with concrete, and a masonry wall is built above the level of the low water up to girder level. A bridge was carried away by being filled to the brim, and then struck by heavy floating timber, but the foundations stood firm, the pier turning over on its side.

Foundations to bridges.

Where timber and stone are abundant, a very sound and efficient foundation has been obtained by the use of cribs, which are large crates of timber, floated into their place, then filled with stone, and thus forced down into the bed of the river. These are more durable than piling, which is avoided, except where creosoted timber can be obtained.

Rolling loads and weights of bridges.

Very little saving has been effected by the narrowing of the gauge in India, so far as the superstructure of the bridges is concerned, the width being still sufficient for the Broad Gauge Rolling Stock. Whether the Government have thus arranged with an eye to a probable widening of the gauge hereafter does not appear. On the other hand, great economy has resulted from the reduction of the rolling loads, as may be seen from the following Table, which gives (1st) the Rolling Loads for English bridges, as prescribed by the Board of Trade; (2nd) the number of tons in the superstructure of a bridge of several spans, designed for those rolling loads; (3rd) the Rolling Loads adopted for the Metre Gauge in India; (4th) the weight of bridge designed for these latter loads.

TABLE OF ROLLING LOADS AND WEIGHTS OF BRIDGES.

Rolling loads and weights of bridges.

Span of Bridge.	English Board of Trade.		Indian Government.	
	Gauge, 4′ 8½″.		Gauge, 3 3⅜″.	
	Rolling Load.	Weight of Bridge.	Rolling Load.	Weight of Bridge.
Feet.	Tons.	Tons.	Tons.	Tons.
20	44	5	20	2·5
30	53	8	30	5
40	62	12	40	7
50	70	16	50	11
70	93	30	62	22* 14†
150	180	110	110	72

* Load on bottom. † Load on top.

A considerable saving also results from platforms being dispensed with, the bridges being open between the girders, the rails being carried on longitudinal timbers, and a single plank provided for the workmen.

Girders.

For spans up to 60 feet it is found that plain plate girders are the most economical; beyond that lattice girders; and for very large spans trussed girders with links and pins. This last form of bridge has the great advantage of being very portable. No piece, for a bridge of 150 feet span, need exceed 15 feet in length, nor weigh more than a few cwt. Such a bridge is put together in the maker's yard, then carefully marked, taken to pieces again, and carried on muleback, or in light carts, and very rapidly erected without much riveting, and with the certainty of every part fitting correctly. It is hardly within the scope of the present lecture to examine the details of such bridges, suffice it to say that the proportions of the various parts were determined after a series of full-sized experiments, and that the great object is so to arrange the material, that the strains upon it may be as far as possible direct, and to avoid cross-strains. It is necessary, in order to avoid vibration under passing loads, to well-stiffen the platforms, and in large bridges the top members of the girders also. It is on many of these railways impossible to incur the expense of iron girders, and very strong bridges, even up to large spans, are in such cases constructed of timber, which if well protected and looked after, will last 20 years. Bridges of this kind commence with a simple baulk of timber trussed, to carry the locomotive, and run up to spans of 150 feet. The Howe truss is the usual form adopted. In some cases the main girders are of iron, and the cross girders of wood.

Rails.

The permanent way of the railways in question is very different indeed from that of an English main line, and here it is that one of the chief savings is effected. Two sections of rail are exhibited, one a 75-lbs. double-headed rail for a 40-lb. chair, such as used on main lines here, the other the rail weighing 41 lbs. per yard in steel, and laid without chairs, used

Rails.

for the mêtre gauge lines of India. The former is secured at each sleeper by two spikes and two trenails, and by keys, the latter by dog-spikes only. Fishplates are used in either case, but of different dimensions. In some cases rails of 30 and 36 lbs. have been adopted, but they are too light, and are being gradually replaced by rails weighing at least 40 lbs., and in some cases, 50 and 56 lbs. per yard. The introduction of steel for rails, by which they are rolled from solid cast ingots, and are thus free from welds, instead of being constructed as are iron rails from a bundle of bars, has very much assisted in the use of lighter weights, although it is only of late that the price has been so reduced, as to render steel rails available for cheap railways. These light rails answer well if the rolling loads are properly proportioned, the sleepers not laid too far apart, and the speeds regulated.

Sleepers.

The sleepers are spaced generally 2,000 to the mile, and are sometimes half-round, 6′ 6″ long × 9″ × 4½″, in other cases 7′ × 6″ × 5″ rectangular. Those for India are of Baltic timber, creosoted under pressure; in Brazil, and in Canada native timber is used. In India the half-round sleepers are laid round side down.

Mr. Wood of Middlesborough has introduced a form of wrought iron sleeper, which is specially adapted for light railways, is very portable, and, at present prices, as cheap as wood. Of this a model is exhibited.

The chief difficulty with this light permanent way is to keep the gauge, especially on curves. The use of hard wood sleepers, such as teak, in such places is an effectual remedy, as it gives the spike a firm grip. Fangbolts, six to each rail, which pass through the sleeper and grip the underside, are in some cases used to keep the gauge. Where, however, frosts are severe, they cannot be adopted with advantage, as the rails have, when the ballast and sleepers are firmly frozen together, to be levelled up by the use of shims of oak, or other hard wood, driven in between rail and sleeper, and fangbolts in such cases are often frozen so hard that they cannot be moved.

Ballasting.

Ballasting is often neglected; it is one of the last things to be done, and the purse is often growing empty by the time its turn comes. It is, however, an essential element of stability in a railway, and the narrow gauge railways in India are very well cared for in this respect. Ballast consists of gravel, coarse sand, laterite, burnt clay, or in the absence of anything else, the driest earth that can be found.

Stations.

There is no item, under which greater savings can be effected, than that of stations. By a little modification of carriage steps, platforms can be avoided altogether. On the Indian lines this is, however, not the case. Buildings are generally most suitable which are built of the usual design and materials of the country. Where trains are slow and infrequent, signals can be reduced to a minimum, a distant signal each way being quite enough to protect the station, and, in some cases, even these are dispensed with, and the trains are worked by a telegraphic train-dispatcher, who controls the whole system, and adjusts the crossing of the trains hour by hour. The water supply must never be stinted, and too great care cannot be taken about it. The quality of the water is of equal importance with the quantity, but is often altogether lost sight of. Furred boilers, frequent stoppages, and heavy expenses are the result. The use of a very simple form of chemical analysis would prevent this.

Water for engines.

On one of the Canadian narrow guage lines the very effective and economical plan for supplying water devised by Mr. Haggas has been

Water for engines.

adopted. This consists of an injector, similar in principle to that now so generally used for forcing water from the tender into the boiler, and by which with the surplus steam water is forced into the tender at the rate of 400 gallons per minute, from brick tanks or even barrels placed in the ground. All overhead tanks, tank-houses, and pumping engines are thereby rendered unnecessary.

Locomotives.

The chief mechanical difficulty in connection with railways of narrow gauge is the undue limitation of the width of the firebox of the locomotive, which cannot be wholly compensated for by length. If, however, the gauge is not less than 3' 3⅜" this difficulty is not serious, and very excellent, powerful, and economical locomotives are constructed.

Light railways are generally constructed with such a view to economy of first cost, that curves are of very frequent occurence. These combined with light rails and insufficient ballast, call for the use of the Bogie-truck for the leading wheels, either in the American swing-bolster form, or in the excellent form designed by Mr. W. Adams, of the London and South Western Railway. The object of this truck is to allow, not only for radial movement, which can be accomplished by other means, but also for a rolling motion to compensate for inequalities of the road, for which it is quite unequalled. Care is also taken to keep down the weight upon the wheels within such limits as the weight of rail requires. A very common error, even by some of the best makers, is to place the centre of gravity of the boiler too high, and the cylinders too far apart, both prolific causes of oscillation, naturally most destructive to light permanent way. The driving wheels are kept of moderate diameter, as speed is not aimed at, and the tractive power of the engine is thereby much increased.

Where the gradients are moderate and the loads light, it is a great advantage to have only four wheels coupled, but six wheel coupled engines work very well at low speeds, by giving a little play in the brasses, and leaving one pair of wheels without flanges.

Many types of locomotives are to be found on these railways, but all have outside cylinders.

In Norway, tank engines are employed, weighing 14 tons in working order, and having cylinders 10 inches in diameter, with a length of stroke of 18 inches. They have six wheels, four being three feet in diameter and coupled, and the leading wheels being two feet in diameter. They burn coal.

In Queensland and Canada, the favourite class of engine has six wheels coupled, (but placed very closely together, giving a wheel base of 7' 2" only), 3' 3" in diameter, with a leading bogie, having 2' wheels, cylinders 11" in diameter by 18" stroke, and 600 feet of heating surface, and weighs 21 tons. They make in Canada, a daily run of 122 miles. They run 68 miles whilst consuming a cord of wood of 128 cubic feet, or 125 miles, with 2,000 lbs. of bituminous coals. They have tenders weighing 9 tons, carrying 600 gallons of water.

The latest type on the South Indian Railway has its four leading wheels 4' in diameter coupled, and its trailing wheels are 2' 4" in diameter. The cylinders are 13" × 20"; the heating surface 665 square feet. This engine weighs 18 tons. The tender weighs 12¼ tons when full, and carries 1000 gallons of water, and 88 cubic feet of coals. These engines run very steadily at 20 miles an hour. For the goods traffic, and to run at 15 miles per hour, engines are employed precisely similar to the passenger engines, except that their six wheels are all 3' 3" in diameter, and coupled.

Locomotives.

Play is given by the Cartazzi axle-box which has inclined planes on its top. The [illegible] being then only partially [illegible], the engines are fitted with pumps or [illegible], and with very powerful head lamps, having large reflectors so that the driver may see well ahead. A small plough attached to the front is useful in clearing moderate snow.

Rolling stock.

The description of rolling stock employed varies very much. In India the general arrangement is, allowing for certain detailed adaptations to the requirements of the traffic and climate, much after the English fashion—in Canada, Brazil, and elsewhere it more closely resembles the American design.

It is important to notice, (1st) that the width determined on for rolling stock will much more affect the cost of the railway and the cost of working the traffic than the gauge or width between the rails: (2nd) that on English railways the width on the standard gauge of 4' 8½" is far less than it might have been with safety, if the centre of gravity had been somewhat lowered.

The width actually adopted varies very much. In India it has been restricted to 6' 7½" on the mètre gauge, thereby perforce rendering both carriages and wagons comparatively inefficient, and at the same time a width for the works, such as bridges, has been fixed, which would have admitted a much larger dimension. In Brazil and elsewhere the maximum is fixed at 8' for passenger carriages, and 7' 6" for wagons, but on the 3' 6" railways of Canada passenger carriages 8' 8" wide, and wagons 8' wide have been running for years with safety and efficiency.

It is manifestly a great disadvantage to fix a too narrow limit of width, as thereby the length of trains for the same amount of traffic is proportionately increased; and as the wheel-base cannot be extended beyond fixed dimensions, the number of wheels and axles becomes also increased, and with them the axle friction.

The mistake has been frequently made of adopting wheels of very small diameter, but this has been found to have so serious an effect upon the cost of haulage, that the diameters are being increased wherever possible, and 2' 6" and 2' 4" substituted for 2'. On most of these railways, the opportunity afforded by a change of system, has been embraced to substitute central buffing for the side-buffing of the English, and other railways. In America, central buffing and draw-gear has been the rule on all the railways, the coupling generally having been of the simplest form with link and pin. Mr. Carl Pihl, the Norwegian Government Engineer, who may fairly be considered the pioneer of the 3' 6" gauge, introduced the central buffer and draw-gear, which, with slight modifications, has been more generally adopted than any other. It consists of a strong hook hinged on a stout pin passing through a wrought iron buffer head, which is hollowed out to receive the hook. The hook engages itself with a similar pin in another jaw in the opposite buffer head, and a bridle falling down over the hook prevents its jumping out. The hook can be attached to either buffer-head. The pull and thrust respectively come upon india-rubber, or steel springs placed sometimes at each end of the vehicle, sometimes in a wrought iron cradle in the centre of the under frame. There are no safety-chains in some cases, in others only one placed below the coupling in others two as in England. The chief objection to this arrangement is that the coupling is not tight, and that the play allowed often causes shocks to passengers upon the starting and stopping of trains. Efforts are now being made to remedy

Rolling stock.

this evil, by applying a screw to the pin carrying the hook, but the matter is not free from difficulty. A coupling which is rather more simple, but which also is not tight, is that known as "Ibbotsons," of which a model is shown.

The centre of gravity of narrow gauge stock is kept as low as possible, a common dimension for the centre of buffers being 1′ 10½″ above rails, as compared with 3′ on English railways. To effect this the springs are sometimes hung inside the sole bar, but the arrangement which is now considered the best is shown on the diagram, which gives a plan and sectional elevation of a carriage underframe, and shows both the bearing, and the buffing and drawing springs.

Where American chilled wheels of solid cast iron are available, they have been used with great advantage both as regards simplicity and durability. The wheels, when sent from England, have been generally of wrought iron with Bessemer steel tyres.

As in the locomotives, so in the rolling stock, radiation of the axles is often of importance. The bogie-truck gives all the flexibility that can be wished, but it has the disadvantage of not supporting the underframe in the centre; so that carriages and wagons constructed upon this system are comparatively heavy, as compared with ordinary four-wheeled stock. Flexibility without this drawback is very well effected by Cleminson's system, of which a model is exhibited, and which is lighter than ordinary six-wheeled stock, and very much lighter than American stock.

Festiniog and other light lines.

The Festiniog Railway in North Wales is interesting as an example of the successful application of steam power to a tramway of 1′ 11½″ gauge. This line is some 13 miles long, and has gradients of 1 in 80, and curves 1¾ chains radius. It is laid with double-headed rails 49 lbs. to the yard, and is partly worked by locomotives upon Fairlie's patent. These have a central firebox, which coming between the wheels is not limited in width by the gauge. The boiler is carried upon two bogies, each having a pair of cylinders and motion complete, and the engine is very flexible, and takes sharp curves readily. For an exceptional case such as this it is useful. The carriages are only 6′ 3″ wide, and the passengers sit back to back, as in an Irish outside car. This railway is worked very cheaply, but this is accounted for by the fact that its heavy traffic is in slates, which are very compact, and that the load is chiefly carried downhill from the quarries to the sea. Thus no fair comparison can be made between this and any ordinary railway, having equal traffic in both directions.

The Broilthal Line in Germany, has a gauge of 2′ 7″, with curves of 124 feet radius; gradients of 1 in 70. The rails weigh 24 lbs. to the yard. The locomotives weigh 12½ tons.

A gauge of 2′ 9″ has been adopted for two very important lines in the United States, the Denver and Rio Grande in Colorado, and the Southern Pacific, and on numerous branch lines. The advocates of very narrow gauges in America are very enthusiastic in their favour, and by considering all their trains as completely filled, and comparing them with trains on the 4′ 8½″, only one third filled, arrive at the paradoxical result, that an engine of the same weight on the 3′ gauge can actually haul a much larger paying load than on the 4′ 8½″. It need hardly be said, that to attribute this result, even where it attained, to the gauge is an entire fallacy, and simply points to the importance of using wagons of moderate length and avoiding such heavy and lumbering vehicles as are the ordinary freight class of the States, which, being many of them 28 feet long, are almost certain to run half empty, except when used for heavy through traffic.

The Railway from Shanghai to Woosung, 9 miles in length, although very short-lived—having been pulled up by the Chinese authorities—worked very successfully for a time, and carried very large numbers of passengers. This line was on the 2′ 6″ gauge, laid with 26 lb. iron rails secured to 2,200 wooden sleepers per mile, and well ballasted. It was worked by locomotives weighing respectfully 9 tons, and 12 tons. The ordinary speed was 18 miles an hour.

A railway has just been completed as a branch from the Great Eastern, in Essex, which has a gauge of 3′ only, thus involving break of gauge. It is an easy line, having only two bridges of any importance, and two intermediate stations. The formation width is only 8 feet, and the permanent way consists of 30 lb. rails, laid on 2,200 wooden sleepers, 6′ × 6″ × 3″ per mile, and well ballasted. The stations are very simple, and the signals are placed close to the points and locked with them. The line is worked by locomotives weighing 12 tons, having four coupled wheels, and a pair of leading wheels with sliding axle-boxes. The passenger carriages are upon the omnibus plan, with six wheels upon Cleminson's plan. Each carriage holds 10 first-class and 20 third-class passengers, and weighs 4½ tons empty. The wagons are also very light. This line is worked under the Light Railways Act, and by train staff, which acts as a key for a swing bridge which has to be opened very rarely. The cost of transhipment of coal at the junction is 4d. per ton.

The Isle of Man Railways are on the 3′ gauge, and have rails weighing 45 lbs. to the yard. The Ballymena and Larne Railway in Ireland, is a short line also of the 3′ gauge.

Cost of light lines.

Passing in conclusion to the important question of first cost, the following summary may be of interest. It is, however, impossible to fairly compare different lines in this respect, as so much depends upon local circumstances, and especially upon the cost of labour: thus, a cubic yard of earth which in India could be moved for 4d., would in some parts of the world cost over 2s., and sleepers which are a drug in Canada, are very costly in India.

	COST PER MILE.
Queensland Railways, 3′ 6″ gauge	£8,600
Shanghai and Woosung 3′ „	7,000
South Indian Railway, 3′ 3⅜″ „	6,500
Ballymena and Larne Railway, 3′ gauge	6,500
Isle of Man Railway, 3′ gauge	6,300
Norwegian Railways, 3′ „	3,000 to 6,000
Canadian Narrow Gauge Railway, 3′ 6″ gauge	4,000

in all cases including land, stations and rolling stock.

The Essex Line has cost £3,000 per mile, exclusive of locomotives and rolling stock. The Broilthal line is said to have cost £2,000 per mile, including everything.

The duty of the Engineer, upon whom may devolve the design and superintendence of works of this class may shortly be summed up thus:—

Design of light lines.

1st. Avoiding break of gauge, wherever possible, to fix upon such a gauge as will most effectively answer to the special circumstances, not going below three feet, if it can be so arranged.

2nd. To decide upon the loads to be carried, and the speed required, and to adjust all the details of construction accordingly.

3rd. Not to unneccessarily narrow the rolling stock.

4th. Whilst studying economy of first cost, to keep a careful watch over the efficiency of the several details, lest the cost of working should be enhanced.

5th. To be very sparing in the use of sharp curves.

6th. Not to adopt rails of too light weight, and to be very careful to secure them well.

From the foregoing it will be seen that the saving to be effected in first cost depends chiefly upon the following points, placed somewhat in proportion to their relative importance:—

1st. The rolling loads, or, first, load per axle, and, second, load per foot lineal of loaded train.

2nd. The maximum speed required.

3rd. The width of the rolling stock.

4th. The gauge of the railway.

5th. The amount of the station accomodation required.

TEMPORARY EXPEDIENTS IN RAILWAY CONSTRUCTION.

BY

CHARLES LEAN, Esq., M.I.C.E.

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Introduction.

THE short time which has elapsed since I was asked to give this lecture, only three or four weeks ago, and the pressure of my regular business must be my excuse if, in speaking on this subject, I fail to do so as thoroughly as might be desired, or if I omit to refer to many temporary expedients which are of great value both to the civil and military engineer. It must also be remembered that I am a civil engineer, and do not profess to be *au fait* in the special requirements of the military engineer. I will, however, lay before you as completely as I can in the time at my command, the various temporary expedients which appear to be most useful in engineering works involved in the construction of railways.

Temporary expedients in railway construction may, I think, be very properly divided into two classes. First, there are those expedients which are used in the construction of permanent works, such as the methods of erecting the piers or superstructure of bridges, and second there are temporary expedients which, for the time, discharge the duty to be ultimately performed by the permanent works when complete.

Amongst these are temporary bridges thrown across rivers to do the duty of the proposed permanent structure during its construction, and possibly to assist in the work of its erection, and also light surface lines of railway, which may be used as a temporary expedient, either to carry the traffic between the points to be served by the proposed permanent railway when constructed, or to communicate between points where the heavier works are being carried on on that line.

With regard to railway construction, the temporary expedients must also be further divided into the following branches:—1st, earthworks, 2nd, bridges, and 3rd, permanent way. It is under these divisions that I propose to treat the subject before us.

EARTHWORKS.

Amongst the temporary expedients of the first class used in earthworks are the means used for removing the materials of the cuttings to the embankments where they are to be deposited. In England this is done by wheelbarrows, dobbin carts, or waggons known as contractor's waggons, which are made to tip up either on the side or end, the former being used in increasing the width of an embankment or to get rid of surplus material, and the latter in extending the length of the bank.

EARTHWORKS.

The latter are usually "galloped" to the end of the embankment where the wheels are suddenly shragged, and the contents of the truck are shot out at once. In India the natives prefer to scrape the earth into little baskets which they carry on their heads to the site of the embankment where they empty them. In places where buffalo or ox hides are easily obtained, they are tied to sticks so as to bring up the sides and form a receptacle for the earth. When filled, they are drawn by horses, with extemporised harness, to the proposed embankment, and are emptied by turning the horse back over them. In forming embankments in sidelong ground it is generally necessary to cut trenches along the sloping ground to prevent the newly laid earth from slipping down.

Steam Navvy.

For moving large masses of earth the Steam Navvy (*Fig. A*) is a very expeditious and cheap instrument. It consists of a travelling carriage, running on rails, and carrying an engine and powerful crane; the peculiarity being that the jib is fitted with a moveable arm, at the end of which is a bucket with strong steel teeth, or a cutting edge for soft ground. The bucket is lowered to the ground with its teeth close to the face of the cutting, and by drawing it up by means of a chain at the end of the jib it cuts a slice out of the earth sufficient to fill itself. It is then swung round until it is over a truck brought near for that purpose into which it is emptied through a moveable bottom in the bucket. A machine of this sort, with an engine of 10 HP., will excavate 300 or 400 cube yards per day, and it will work in almost any soil except rocks and hard shale.[*]

Blasting rock.

Hard rock is loosened from its bed by blasting with gun powder What are known as small blasts are those which occur in railway practice in which the bore hole used as a receptacle for the gunpowder is not more than 6 inches in diameter. The holes are made by an instrument called a "jumper," which is an iron bar with a steel point in the shape of a chisel, and is jumped by hand or by means of a rope attached to its upper end on the rock until the hole is formed. The jumper is turned slightly round at each blow, and the rock in the hole being reduced to dust may be brought away either by water, or by a scoop. It is sometimes necessary to use a hammer to strike the jumper if the rock is hard, one man striking and another turning the jumper; and sometimes the whole operation is performed by specially contrived machinery, as rock drilling machines, &c. When the hole is properly formed and made quite dry, the powder is poured into it through a tube reaching to nearly the bottom of the hole, one end of a fuze is inserted in the powder and the other end brought to the surface. The hole is then filled up with either chips of rock or dry clay and carefully rammed with a tamping bar.

A blast gives the best results when the line of least resistance in the rock to be moved is at right angles to the bore hole, and the worst results when the line of least resistance is the bore hole itself. Thus the line of least resistance is the distance from charge to surface (*a*) in *Fig. B.* and (*b*) in *Fig. C.* A test for the quality of blasting powder is that 2 ozs., or $\frac{1}{8}$ of a pound avoirdupois, of it being fired in an 8-inch mortar elevated an angle of 45°, should throw a 68 lb. ball to a distance of 240 feet.

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[*] One of Dunbar and Ruston's patent 10 HP. Steam Navvies, working in a gravel and clay railway cutting, 16 feet deep by 25 feet wide, advanced 12 yards in a good day's work, in 6 shifts of 6 feet each. Three scoops filled a truck in 2 minutes, including shifting truck. In good weather and easy soil, 20 wagons per hour were filled and despatched by 10 men, or 200 wagons per day of 10 hours, whilst by hand labour, 3 men filled 16 wagons in 10 hours. The contractor did not consider it worth setting it to work in excavations containing less than 100,000 cubic yards. More work can be done where the navvy can feed a wagon on each side, as it never has to wait for an empty wagon.—ED.

Blasting rock.

The volume of rock which is moved with a blast is generally about equal to twice the cube of the line of least resistance, that is, that (*a*) cubed and multiplied by 2 would be the amount of rock moved by the blast at (*c*) in *Fig. B.*, but (*b*) cubed × 2 in *Fiy. C.* The weight of rock moved may also be approximately estimated as being equal to 10,000 times the weight of the powder used, or the powder required may be taken as equal to the weight of rock to be moved divided by 10,000. The formula for calculating the weight of powder required for a small blast is:

$$\text{Powder in lbs} = \frac{(\text{line of least resistance})^3}{32}$$

Take the following as an example:—

Assume the line of least resistance (*a*) in *Fig. B* or (*b*) in *Fig. C* to be 3 feet, the weight of the powder required will be $\frac{3 \times 3 \times 3}{32} = 13\frac{1}{2}$ ozs., and the quantity of rock moved would be two cubic yards or 3 × 3 × 3 twice, and assuming it to weigh 39 cwt. to the cube yard, which is an average weight for hard rock, its weight would be 8,736 lbs., or about 10,000 times the weight of powder used.

Great blasts are used in cases where there are very large masses of rock to be removed. A heading is usually driven into the rock ; a chamber is then excavated at the end of it, and when filled with powder and the proper arrangements made for firing by electricity, the mouth of the heading is filled up, and the charge fired. In this form of blasting, the weight of rock moved does not bear so large a proportion to that of the powder as in the small blasts, but it often allows of a considerable saving of time in carrying out the earthworks.

Tunnelling.

Tunnelling is a work of engineering also involving temporary expedients of the first class. Tunnels (*Fig. D*) are very undesirable things in the construction of a railway, but there are occasions where they are absolutely necessary. In estimating the desirability of constructing a tunnel in preference to an open cutting, the cost of the latter must be compared, not only with the cost of making the tunnel, but with the time which will be lost in so doing, because a tunnel is not only an expensive but a tedious work In constructing a tunnel a heading (*Fig. E*) is usually driven along what is intended to be the crown of the tunnel when conplete. Poling boards carried on timbers are used to support the material until a convenient length has been excavated. When this has been done the end is boarded. The upper end timber is then inserted and strutted to the existing work to keep it in its place; the heading being widened and extended. The timbers below it are then got into place (*Fig. F*), and then another main cross timber inserted until the length has been excavated, and the sides and end of it have been boarded. The excavation must be carried to such a width and height that the boarding will be outside the proposed brickwork of the tunnel, which must now be completed as rapidly as possible, and the space between the brickwork and the sides of the excavation filled up with concrete.

It may be necessary during the construction of a tunnel, if of great size, to make a railway along another route to carry the traffic until it can be passed through the tunnel. In such a case as this the earthworks should be the lightest possible, which point is obtained on sidelong ground by contouring the surface to find a suitable centre line for the track, and in other cases by taking considerable detours to avoid hills, &c. Very steep gradients may be unavoidable on such a line as this, and this will

Tunnelling. necessitate either that the ordinary engines should take very light loads, and so work at a disadvantage, or that special engines should be constructed. Either of these expedients, however, would involve working expenses which would be done away with on the completion of the permanent line. In laying out a line of railway the problem is to convey a certain load W from a point A to another point B, and although theoretically the expenditure of power to do this is the same, whatever the rate of inclination of the gradients may be, still, if the difference in elevation of the two points is considerable in proportion to their distance apart, by taking a circuitous route, easy gradients may be obtained which will admit of the line being worked by light and cheap engines. On the other hand it must be remembered that the power expended in overcoming friction, resistance from side winds, irregularities of the tract, &c., increase directly as the length of the line.

BRIDGES. Of bridges there are many kinds and forms, for each of which different forms of temporary expedients are applicable. The work of bridge erection may be considered in two parts: first the piers, and second the superstructure.

Timber piles. The piers of bridges crossing rivers or valleys where the ground is composed of clay or other soft material are often formed of timber piles, which are long pieces of timber shod with iron at the bottom and driven into the ground by a falling weight. A stage or barge (*Fig. G*), carrying a winch and a guide for the falling weight or monkey, is fixed close to the spot where the pile is to be driven, and so arranged that the pile shall be in the line of the fall of the monkey. The monkey is raised by the winch, and upon passing a certain point it is released and falls upon the top of the pile. The process is repeated until the pile is driven to the required depth. This is generally ascertained by the amount of resistance which the pile offers. The safe load on a pile is calculated from the following formula:—

$L = \frac{W\ H}{8\ D}$ where L is the safe load in cwt.

$W =$ weight of monkey $= 4$ cwt. in ordinary pile engines.

$H =$ height the monkey has fallen in inches, and

$D =$ set of the pile by the last blow in inches.

Example:—Suppose the pile moves $\frac{1}{4}$ inch. with a blow from a 4 cwt. monkey falling 10 feet, then $L = \frac{4 \times 120}{8 \times \frac{1}{4}} = 240$ cwt. $= 12$ tons.

Timber trestles. Trestles formed as in *Fig. H* and resting on the bed of the river or valley are often used to save the expense and delay of pile driving. In (1) the ground requires to be made nearly level to give a proper bearing for the sill, and the trestle is kept in its place by the superstructure of the bridge. If there are boulders in the bed of the stream, or if it has an irregular rocky bottom, the sill is sometimes made in two pieces, (2) which allows it to accommodate itself to the form of the bed to some extent, the uprights being braced as shown. Sometimes the sill is dispensed with altogether, (3) and the end of the upright rests directly on the bed rock of the stream.

Timber piers. Piers of considerable height (*Fig. I*) are formed of timber braced together and connected by dowels. Two uprights braced together are raised opposite a similar pair; the feet of both pairs resting upon sills to which they are connected by dowels. Cross sills are then placed upon the tops of these pairs and spiked down to them, connecting them firmly together. Dowels

Timber piers

are then inserted in the tops of the uprights and another set of braced uprights placed on them. In order to prevent a pier of this construction from overturning, it is necessary to erect diagonal struts, which are made in lengths in the same way as the centre portion and braced to it as the work proceeds. If the superstructure can be carried on simultaneously with the piers, and if the spans are not too large, the various parts of the piers can be brought into position by means of a crane (*Fig. J*) or a specially contrived carriage running on the completed part of the bridge.

Iron piles.

Iron piles, both of cast and wrought iron, are often used. The latter are usually driven in the same way as a timber pile, and are made of wrought iron bars riveted together and fitted with a steel shoe. Cast iron piles (*Fig. K*) are made with a blade or large flange (1. *Fig. K*) at the foot; and where they are intended to be used in a clay soil this blade is made in the form of a screw which does not form more than one turn, leaving an opening to allow for passing any boulders which may be met with in the the clay or mud through which the screw passes. A stage (3. *Fig. K*) is erected on temporary piles or trestles at the spot where the pile is to be driven; the pile is carefully pitched so that it may be exactly in its position; a capstan is fitted on the top of it, and by means of long levers, actuated by the power of men or animals, the piles are turned round and screwed into the bed to the required depth. The stage upon which the work is performed must be large enough and strong enough to carry the men or animals required.

If the piles are to be used in a sandy bed a much more cheap and expeditious method may be adopted. The blade of the pile, instead of being a screw, is simply a large flange (2. *Fig. K*), or it may be a disc bolted on to the bottom of the pile. A small pipe is carried down the pile and out at the bottom projecting a few inches below the disc. Water is pumped down this small pipe (4. *Fig. K*), and this loosens the sand round the pile, which, with very little movement, will sink readily to the required depth. When the pile is as low as it is intended to put it, it must be supported until the sand has firmly settled round it which it will soon do when the pumping has ceased. Piles in sand can in the same manner be very easily drawn out if necessary. Water being pumped through them as before, the sand soon becomes quite loose all round them and they can be readily raised. Piles driven in this manner and also screw piles in stiff clay will generally carry a load of about 5 tons per square foot of the blade or disc upon which they rest.

Cast iron piles are liable to be broken if they are in positions where they may receive blows from vessels, and in such positions they are sometimes protected by timber piles outside them or by dolphins and fenders. In some cases that part of the pile which it is expected may receive injury is made of wrought iron instead of cast.

In very soft deep mud, where piles would go to a very great depth without coming to a bearing, the piles are not driven to their full depth, but when they have gone to a sufficient depth to prevent lateral movement cross timbers are firmly fixed to them at the level of the surface of the river bed, forming a stage upon the mud, and this ultimately takes the load on the bridge.

Cylinder sinking.

Cylinders of cast or wrought iron are also used to form the piers of bridges. In very deep water the length of cylinder required to reach from the surface of the water to the bed, would be more then could be well carried by the rafts, barges, or pontoons from which the work

Cylinder sinking.

being carried on. To get over this difficulty, a false bottom is used which makes the cylinder a closed vessel and causes it to be buoyant as it enters the water. Cylinders are usually made in rings subdivided into segments; the first ring being a curb with a cutting edge. A portion of the iron work can thus be taken out with the pontoons from which they are to be pitched and the remainder brought out by degrees as it is required.

In erecting large cylinders, two pontoons (*Fig. L*) are fixed together at such a distance apart that the cylinder can be lowered between them. The curb with the false bottom is placed between them and lowered to the water. The rings of iron are successively built upon it, and it is allowed to sink until it rests upon the bed of the river. The false bottom is then knocked out by jumping a rail or heavy piece of iron upon it, the wood of which it was composed floats to the surface and is removed.

In many of the rivers of India and America, many feet in depth of the bed is scoured away during a flood and silts up afterwards. This sometimes takes place to the extent of 50 feet in depth, and in such cases it is necessary that the cylinders should go down to the bed rock.

To do this the earth, clay, or sand requires to be removed from the spot upon which the cylinder stands. If this is done by manual labour the cylinder must be pumped out dry and kept so while the men are at work. This difficulty is got over by the following expedient:—

A kind of boring head or rotary plough (*a. Fig. M*) is used. It is made with cutters or blades arranged in a conical form and is itself carried on an annular pipe. This pipe is supported in guides, and an arrangement is made for working it round either by manual labour or water power. The cylinder is then filled with water to a considerable greater height than the water outside. A syphon is provided consisting of a bent pipe of a sufficiently large size, one leg being in the outside water and the other in the annular pipe. The effect of this is that the water passes up the pipe with considerable force and out through the syphon. The annular pipe being immersed in water is buoyant and self-supporting, and the weight on the plough is easily regulated and does not increase with the depth to which the cylinder goes. The boring head being worked round loosens the earth, and the loose parts, even when of large size, are readily carried up the pipe and out of the cylinder.

It is necessary that the cylinder should be carefully placed in the exact positions which they are finally to occupy, and they then must be guided in their descent to the bed of the river. The pontoons are first very carefully and securely mored, and a chain is passed round the base of the cylinder and connected by pulleys and chains to at least three anchors (*Fig. L*) suitably arranged. By hauling in one chain and slacking two, or hauling in two and slacking one the base of the cylinder may be brought to any position required.

Pneumatic process.

Sometimes large piers are sunk to the bed rock by the pneumatic process, thus:—

A large caisson (*Fig. N*) is formed which becomes the base of the pier and which is large enough for men to work in. It is sunk down to the bed of the river by building upon it, a passage being kept open in the centre of the pier. Air is then pumped into the caisson with sufficient force to expel all the water (doors being formed in the passage upward), the workmen enter and excavate in the bottom until the rock is reached. If it is feared that scour to a serious extent may take place at the piers, a quantity of large stones is usually tipped round them.

Testing foundations.

When the cylinders or piles have been carried as far down as it is expected will be necessary, they are loaded to ascertain whether they will be strong enough to carry the loads which it is expected they will have to bear. This is often done by piling up rails and pieces of iron upon them until they are loaded to from three to ten times the expected load. The proportion of the test load to the real load depends on the nature of the bed upon which the pier rests, the force of the stream, &c., &c. A good plan for performing this test is to provide an iron tank capable of holding water equal in weight to the test load. The tank is placed in the pier and the water pumped in until the required load is on the pier. The water may then be let out and the tank removed to another pier to repeat the operation.

Cofferdam.

Piers are sometimes built entirely of masonry or brickwork, and in order to have the foundations dry for working in the site is enclosed by a cofferdam (*Fig. O*) made of sheet piling (*Fig. P*). Ordinary piles are driven at fixed intervals in the usual manner; waling pieces are notched into and bolted to them, and the steel piling is driven between the waling pieces. When they are all driven in, the water is pumped out and the work commenced.

Getting girders into position.

With regard to the erection of the superstructure, or girders of a bridge, a difficulty is often experienced in consequence of the girder or beam intended to span the opening, being only a little longer than the width of the opening, so that it is impossible to push it directly across from side to side, as the leading end acting as a great leverage overcomes the power at the other end.

With regard to timber beams, or light iron girders, this difficulty may be overcome, thus:—

Two of the beams are fastened together, and the beam to be first run across the opening is placed between them over one cross piece and under another cross piece. The whole being mounted on a roller, or cart, or other axle carried on two wheels, is then run out until the roller is near the edge of the first abutment, and the leading end of the beam is over the opposite abutment, it is then lowered to its position, and the other beams are easily carried over and laid in their proper places.

In erecting one or a series of girders, as in a long viaduct or pier, the girders, which are in such cases generally light ones, may be taken up by a crane on a travelling carriage (*Fig. Q*) and run along the road, or already fixed girders, until they are over the span in which they are intended to be placed. They are then lowered to their places. It is necessary in cases of this sort to provide a special carriage and balance weight for crane.

The sweep of the crane is generally considerable, and unless the carriage is of proportionate length, a very heavy balance weight may be required. Girders for bridges or piers of this nature are not usually designed to carry a large concentrated weight, and this makes it more desirable that the balance weight should be as light as possible. Take the following example: Suppose the span for which the girder is intended has an opening of 20 feet, and the girder was 1 ton in weight. The centre of the pillar upon which the jib of the crane turned would not probably come within 4 feet of the end of the fixed span, the sweep would therefore have to be $\frac{20}{2} + 4 = 14$ feet, and 1 ton at a distance of 14 feet would be the weight to be balanced. If the carriage had 4 wheels, the distance between the front and back pairs being 7 feet, the balance weight would require to be about 2 tons, and this would bring a load on

Getting girders into position.

the bridge, under the first pair of wheels, of 3 tons, plus the weight of engine, crane, &c. If the carriage was 14 feet long, the balance weight would be only 1 ton, and the load under the first pair of wheels would be 2 tons, plus the weight of engine, crane, &c.

In cases where a bridge has to be thrown across a road, or existing railway, the girders may generally be brought on trucks or lorries on the line below, and being packed up on them they can be slewed round until they are diagonally across the road, when they can be easily raised by cranes or by tackle and a shearlegs, to their places on the abutments.

Many cases occur where the girders are necessarily brought to the site of the bridge in small pieces, and require to be put together. Where there is room to do so under the proposed bridge, a scaffolding or stage is erected between the abutments upon which the pieces of the girder can be brought and put together. When this is completed, they are allowed to take their beamings on the abutments, and the scaffolding or false work may be removed.

It will be at once evident that there are many cases where a scaffolding of this nature could not be used; for instance, if the valley to be crossed was very deep, or if the river was very rapid, or if it was dangerous to obstruct the waterway. In many such cases the scaffolding, if not impossible to construct, would be nearly, if not quite, as expensive as the the bridge itself. To overcome this difficulty, the scaffolding is sometimes suspended from the tops of the piers. Wire ropes or cables (*Fig. R*) securely fixed to the piers are carried across the span, two or three at least being used for each span. Cross pieces of timber are laid on the ropes and secured to them, and to these cross pieces the verticals are lashed or spiked, and the diagonals inserted to give the whole sufficient stiffness.

In some instances large girders are drawn over the abutments and xisting girders, upon specially contrived trucks, as far as the new work is fixed. To get over the span to be bridged, two lengths of girders are connected together and securely trussed. (*Fig. S*). A strong vertical strut being erected over the two contiguous ends of the girders, and rods or chains with shackles being carried to the other ends of the girders, so as to make the whole into one large strong girder. This arrangement allows of one girder acting as a balance weight for the other until it is across the opening.

If the girders are very large and heavy, it sometimes may be found impracticable to carry out this arrangement, as the joint weight of two girders and the trussing may be greater than the force at hand will move. The leading end of the girder, when it clears the fixed work, may be taken on a stage carried on a pontoon, and so borne across to the other side. (*Fig. T*). The difficulty in this case is to keep the pontoon or barge carrying the end of the girder in a straight line in passing across the opening, especially if the stream is running fast. This is effected by having two ropes or cables in addition to those used for hauling direct; these two ropes are wound on the same drum or capstan, and are carried to two barges moored at equal distances from the centre line and about half way across the span. By hauling these ropes in on the same drum, or paying them out when the middle of the span has been passed, the mooring vessel is forced to take a straight course.

The truck carrying the land end of the girder need not be elaborate in its construction. A few planks spiked together and being sufficiently strong for the work required to be done, may be run on round logs for rollers, and will often answer all the purposes required.

Getting girders into position.

Bridges which are constructed on the lattice principle may often be erected without scaffolding, by building them out from the piers (*Fig. U*) until the parts coming from each side meet at the centre of the span. To do this, all the projecting portion must be well braced and balanced, to guard against accident, until the junction with the opposite half has been effected. In the case of an abutment, this is done either by attaching the rods connected with the bracing to some natural fixed object, or to anchors built deeply into the ground. When there are more spans than one the work over a pier may be carried on by making portions of girder or arched rib of one span balance similar portions of the next span.

This method is applicable to arched ribs, as on the St. Louis bridge over the Mississippi River, where it was successfully adopted. The arched rib is composed of many parts, and they are so arranged that they can be added one after the other. Thus (*Fig U*), suppose the bay (*A*) to have been erected and tied by the bracing to similar work in the next span, or to the anchors referred to above, the parts *a* and *b* can be connected and fixed in their places, then *c* and *d* and finally *e*. This bay being thus erected, it is then connected with the bracing over the pier or abutment, and another length added in a similar manner. In the case of a very large arched rib, it is economical to have a travelling crane to run on the arched rib, to carry out the various pieces of the structure. The long bracing. rods which connect the rib to the bracing and balance weight, are fitted with shackles or right and left hand screws, so that the whole rib can be raised or lowered slightly if required. This provision is necessary in order to allow for getting in the keying piece of the work As iron expands and contracts to a great extent with heat and cold, it becomes necessary to watch for the proper point of temperature for putting in the last piece of the work, or keying piece. When this point has been found, the ribs are slightly drawn up by means of the shackles, so as to give a little clearance, and the last length inserted.

A method which has been adopted with success for raising large horizontal girders to their positions, is to leave an opening up the centre of the piers when they are being constructed. The girders are then floated out to the spans for which they are intended, and raised up the opening gradually by hydraulic machinery. The hydraulic engine lifts the girder through the length of the stroke, and supports it while the masonry is being filled in under it in the opening left in the piers. When this is done to the underside of the girders they are allowed to rest upon it, the plunger is lowered and a fresh hold is taken of the girder, and it is lifted through another length. This operation is repeated until it has attained its proper level.

Centres for arches.

Arches of brick or stone are constructed by the aid of centres. Centres are usually made of timber, and are trussed frames strong enough to bear the dead weight of the arch.

An ordinary form of centre for small spans is carried on upright timber supports. If it is necessary to allow for the passage of trucks, or a locomotive under the centres, the truss may be divided, each part being separately supported, and both connected at the crown. Still more room is given by making the centre itself an arched rib. This is done by making it of three or four ribs of wood, cut to form the curve on the outside, and securely bolted together. Between the centres and the timbers which support them, pairs of wedges are inserted. By

Centres for arches.

driving them up the centres can be adjusted to the exact height required, and when the brickwork or masonry of the arch is complete, the centres are gradually lowered by drawing the wedges out. The centres are covered over with boards called laggings, running parallel with the centre of the intended arch, and upon these boards the arch is built.

For arches of larger span the centres are differently designed. The curved rib being supported by numbers of struts, carried to an upright pillar and braced longitudinally. Another plan is to support the rib at a number of points by two struts reaching from each point to the timber at the abutments.

Temporary bridges.

The great points are to have sufficient strength in the centre to ensure it carrying the arch until the keystone is put in; and to have the wedges, upon which it is carried, well arranged for slacking the centres down easily. In ordinary civil engineering works, the instances of temporary bridges, or those which come under the second class of temporary expedients, are perhaps not very numerous. They are made on the lightest and cheapest form compatible with their being sufficient for the work they have to do duing the erection of the permanent bridge. The piles need not be driven to the same point of resistance; the timbers need not be of the same size; and the spans, or openings for waterway, need not be so large as they would require to be if the bridge were to be a permanent structure. A fixed temporary bridge may have piers constructed of timber, as already described. A temporary bridge can often be made lower than the intended height of the permanent bridge, which may allow of a saving in earthworks, &c., and it may be necessary to give opening spans in the bridge on this account, to allow of the passage of the traffic in the river which it is intended to pass under the permanent bridge.

Opening spans may be made in various ways. A lifting span is most simple and suitable for a temporary bridge. The main beams carrying the load are cut in two at the centre of the span, and are supported by the struts, which are fastened to them by hinges, so as to hang vertically when the bridge is open. The flaps, or moveable positions of the opening span, are balanced by weights passing over pulley's at the top of uprights fixed near their hinges. These balance weights are so arranged as not to lift the flap without assistance, which prevents the danger of an accident happening by the flap rising up before a coming train.

Another method of constructing a temporary bridge is the following:—Shearlegs are erected (*Fig. X*) on each side of the river, each consisting of three strong piles connected near the top. A wire rope is placed over them, and the ends made fast to two or more trees on the banks. By means of a roller running on the wire, and so arranged that the weight is suspended from its axle, and therefore keeps it from falling off the wire, a load can be carried from side to side of the river. The roller and load are drawn across by means of a light rope connected with the pulley, and passing through an eye or block near the point where the main rope rests on the shearlegs.

If the stream is not rapid, a floating bridge may be constructed strong enough to carry a locomotive engine and train. Pontoons (*Fig. Y*) are provided of sufficient displacement to enable them to bear the load of passing trains. They are moored, if necessary, and connected together by the timbers forming the superstructure or girders of the proposed bridge. In this case, as in many others, rough unsquared timbers may be used for this purpose, the sleepers being half round timbers laid on the others, and having the rails spiked to them.

Wire tramway.

The wire tramway may be considered as a temporary expedient of the second class, and under the head of bridges, although it is really a railway in itself, and perhaps should more properly be considered as a temporary railway. It consists of an endless wire rope, running between the points from and to which goods or earth from excavations, or other materials, have to be carried. This wire is carried on supports, which are placed as may be found desirable, at distances apart varying from 300 to 1,000 feet. The supports may be made of iron or wood, and each carrying two wheels. The wire is kept continually running at a speed of from 4 to 8 miles per hour, by means of a stationary steam engine at one end of the line.

The load to be carried is placed in a small carriage, suspended from the wire rope by means of a curved arm, which brings the centre of gravity of the load directly under the wire, and so keeps it from falling off. The upper end of the arm is fitted with a groved saddle, which clips the wire with sufficient force to make it take the carriage along with it. At each end, or at any point where it is desired to have a station on the line, a platform is constructed of such a level that the wheels of the carriage run on it, and the clip leaves the rope.

The truck may then be emptied and pushed round to the other side of the stage on to the return rope, which the clip immediately fastens upon, and the empty carriage is taken back to the other end of the line. The curved arm prevents any parts of the passing load striking the supports. The carriages usually carry loads of from 1 cwt. to 10 cwt.

Pioneer railway.

The "Pioneer Railway" is an expedient of the same nature as the "Wire Tramway," but is on a larger scale. The railway is designed for economy in very rough countries and where timber can be readily obtained. It consists of uprights of timber securely strutted, and carrying on their tops a longitudinal timber, and on their sides two timbers firmly bolted to them. The locomotive engines and carriages hang over this line on either side, the vertical pressure of the load being taken by the upper timber, and the two side timbers acting as guides. The guide wheels of the locomotive are arranged to act as driving wheels, and are made to clip the side timbers with any amount of force required, and it can therefore take comparatively large loads up steep inclines.

PERMANENT WAY.

Laying roadway.

Under the division of permanent way, the 1st class of "Temporary Expedients" will consist of details in the laying of the permanent way materials of a railway. The formation of a railway, or the surface to which the ground is excavated, or embanked, is made in a curved form to allow water to run off easily. The ballast is then laid up to the underside of the sleepers, and dressed to a fairly plain surface. Upon this the sleepers are laid. For such fastenings as treenails, round spikes, or fangbolts, holes require to be made in the sleepers with an auger. The line is first "linked in," or the fishplates at the joints of the rails are secured with only half their proper number of bolts. The top ballast is then thrown round the sleepers and beaten firmly under them, the road is pulled by levers into its final position, the joints are completed, and the rails are raised to their proper height. This is done by means of a long wooden lever, which is put under the sleeper to be raised. The end of the lever is pulled down over a fulcrum, and while the sleeper is held up, a sufficient quantity of ballast is beaten under it to keep it up at the required height.

On sharp curves it is sometimes necessary to bend a rail to make it fit the curve more nearly than it would do when quite straight. This is done

Laying roadway.

by a tool called a jimcrow, which is a very powerful screw fitted into a bent arm with hooks to take hold of the rails. By screwing up this instrument when the rail is properly placed in it the required curvature is obtained. It often happens that a gap in the rails has to be filled up, and that there is no rail at hand of the exact length required. It then becomes necessary to cut a rail. This is done by nicking it round with a cold chisel at the point where it is to be cut, and breaking it off over an anvil. In such a case as this, the fishbolt holes will require to be drilled afresh. They may be done with a ratched brace and bits of a proper size.

Materials for roadway.

Under the 2nd class of "Temporary Expedients," there are several different forms of permanent way materials for temporary railways. An ordinary contractor's line usually has flat bottomed rails, which are fixed to the wooden sleepers or cross ties by dogspikes, which are pieces of wrought iron from $\frac{1}{4}$ to $\frac{1}{2}$ inch square, with one end sharpened and one end turned over to catch the bottom flange of the rails. In a line of this sort fishjoints are often dispensed with, the ends of two rails being fastened on one sleeper in line with each other. On these lines the switching from one line to another is managed by moving the last rail on the single part of the line, and the crossing is often effected by raising one of the rails, so that the truck running on it will run over the other rails. The "Economical Railway," is the name given to a light form of rail and sleeper all made of iron. The sleepers are formed of bar iron, rolled with a recess on the under side; they are fitted with lugs, or projections, to hold the rails, which are fastened to them by keys or wedges. The rails are fixed in lengths which can be easily picked up by two men and carried to their place on the line. One end of each pair of rails has a clip into which the ends of the next pair are pushed and the joint is complete. Another form is "Legrand's," which consists in a peculiar form of wrought iron sleeper. This is suitable for a heavier rail than the last, which it is evident could only be used for a very light railway. The peculiarity of Legrand's sleeper is, that the lugs to hold the rail are alternately in the inside and outside of the rail. The sleepers which clip the rail on the outside having first been put in their places, the others are put between them and turned until they are at right angles to the rail. The spring in the rail allows of this, and also prevents them turning back or the road from becoming loose. Many other forms of light permanent way materials have been invented; the great aim being to reduce the number of loose parts, and facilitate the laying of the line. This has been so far attained that with a line similar to the "Economical Railway," just described, four men could take up a quarter of a mile of line, and relay it 30 yards further on in less than one hour.

Conclusion.

In countries where timber is abundant, and iron rails cannot be readily obtained, a wooden rail may be made. It consists of pieces of wood with the grain placed vertically, and carried by two longitudinal pieces which are recessed to receive them. The vertical pieces form the rail upon which the tyre of the wheel runs, and can be easily replaced when worn down. The longitudinal may be carried on cross ties or sleepers in the usual manner.

In conclusion, I would say that resource, or the power to invent and carry out successfully temporary expedients in the construction of engineering works, and to make the best use of materials at hand, is one of the most valuable talents which an engineer can possess. This is decidedly the case with the civil engineer and is much more so with the

Conclusion.

military engineer, who in active service must often meet with many unforeseen circumstances, which, when they arise, must generally be dealt with at once, giving very little, or no time, for considering the best method to be adopted. This power should be cultivated sedulously by all the actual experience attainable, and by the solution of hypothetical problems. One of the first steps in this direction is the attainment of a thorough and accurate knowledge of the strength and properties of materials obtained from actual experience or experiment, or other reliable source; and another is the attainment of a complete knowledge of the principles of construction and the laws of statics and dynamics.

I hope, gentlemen, that I have made myself intelligible and clear in the matters which I have endeavoured to lay before you, and I thank you very much for your kind attention throughout.

PLATE. I.

FIG. A.
STEAM NAVVY.

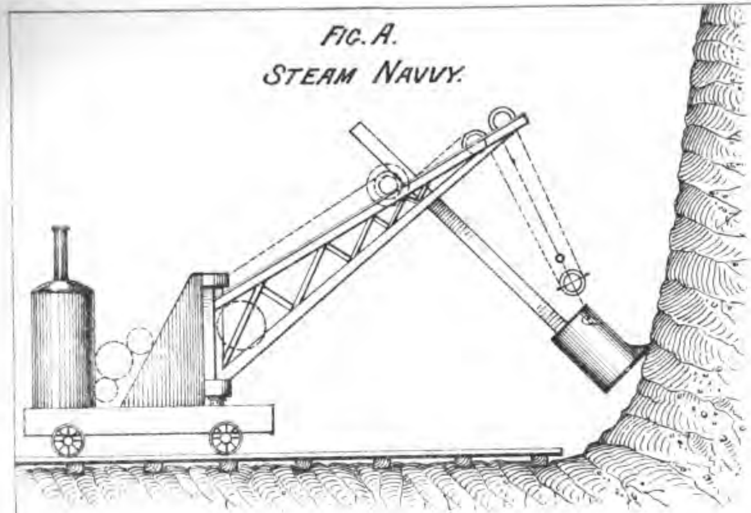


FIG. B.

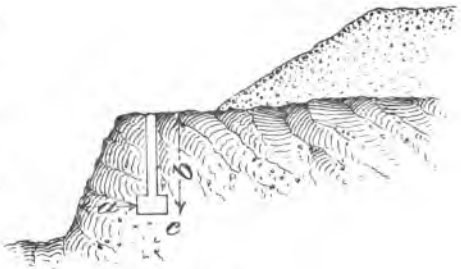
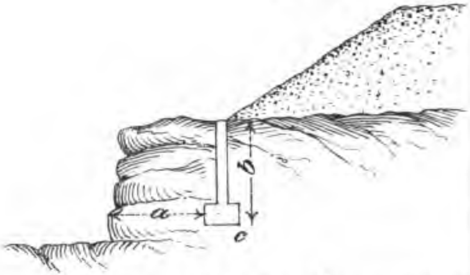


FIG. C.



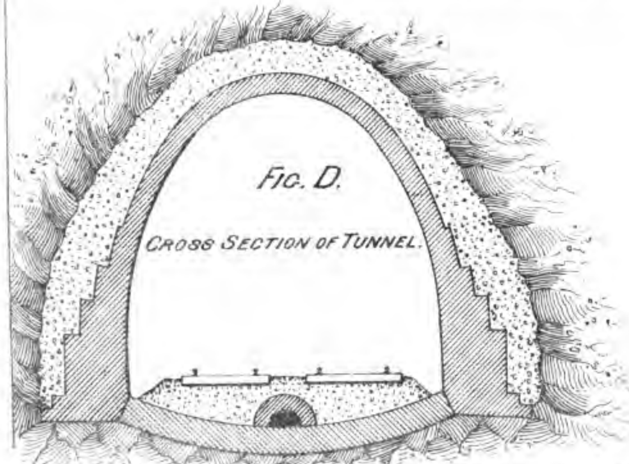


FIG. D.
CROSS SECTION OF TUNNEL.

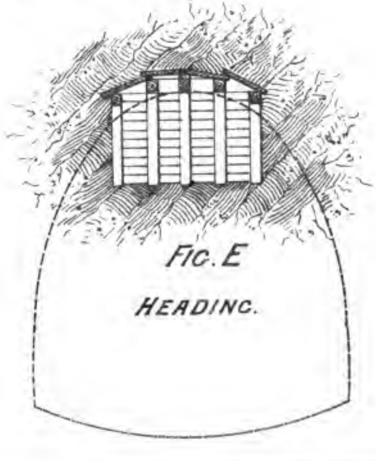


FIG. E
HEADING.

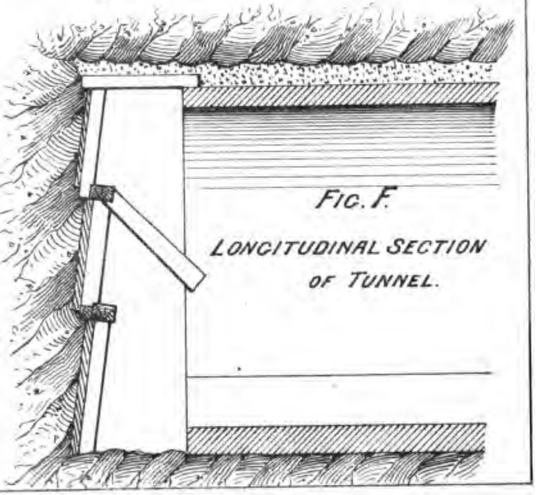


FIG. F.
LONGITUDINAL SECTION
OF TUNNEL.

PLATE 2.

FIG. C.

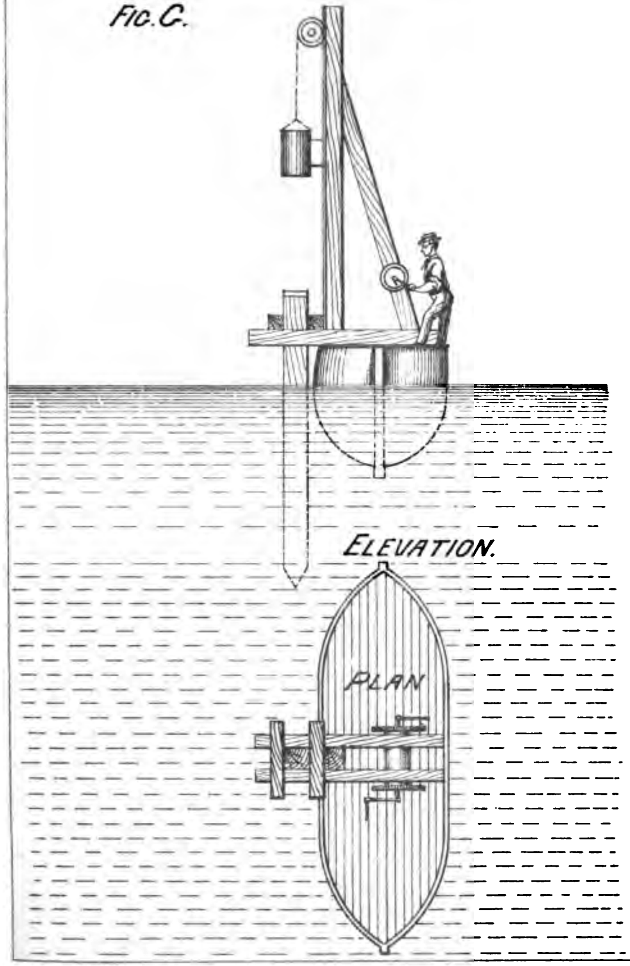


FIG. H.

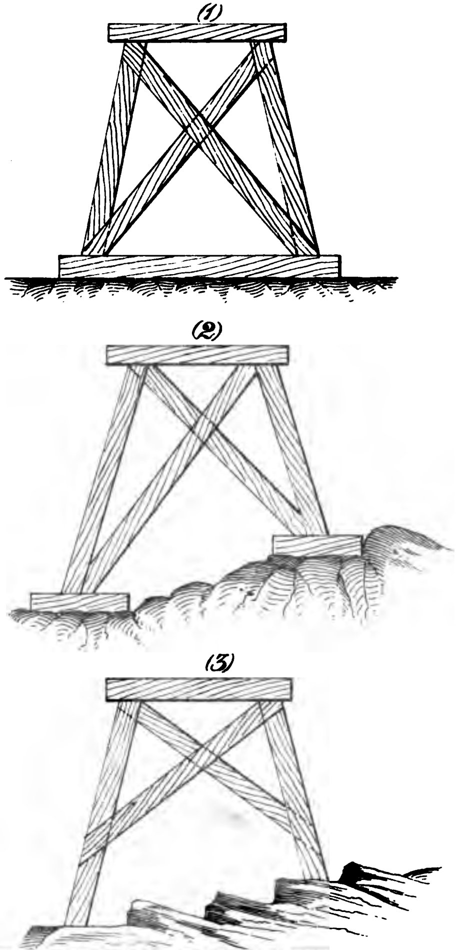


FIG. I.

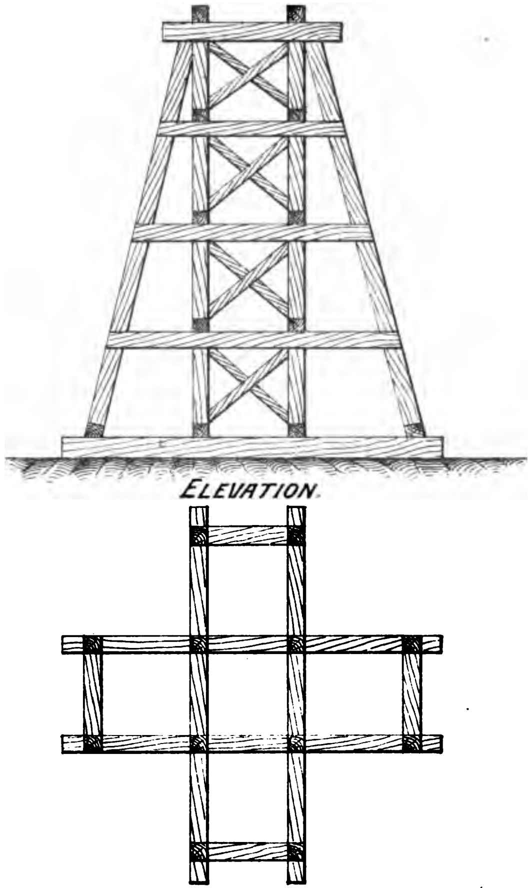


PLATE. 3.

FIG. J.

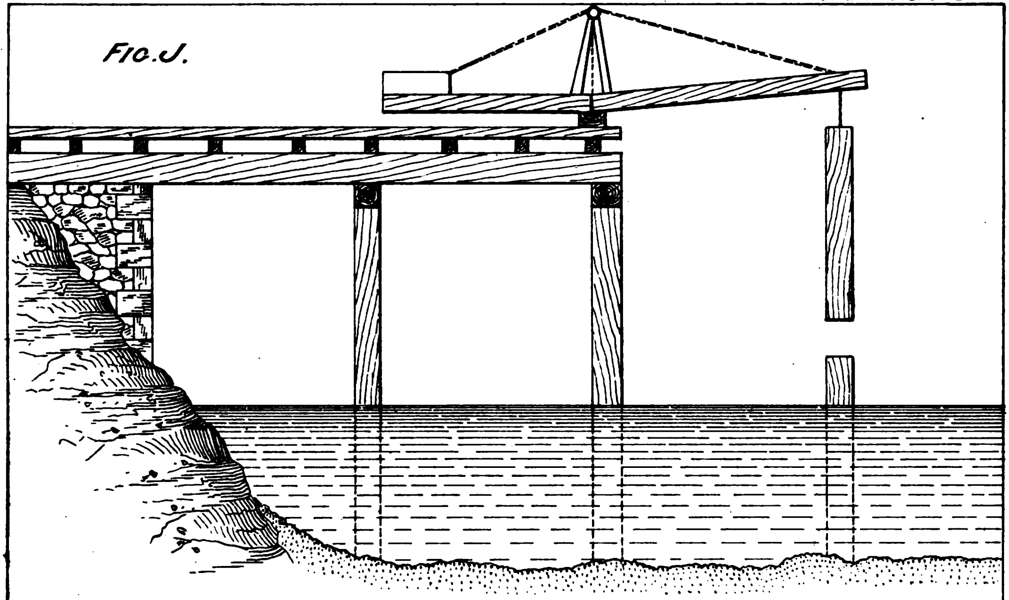


FIG. K.

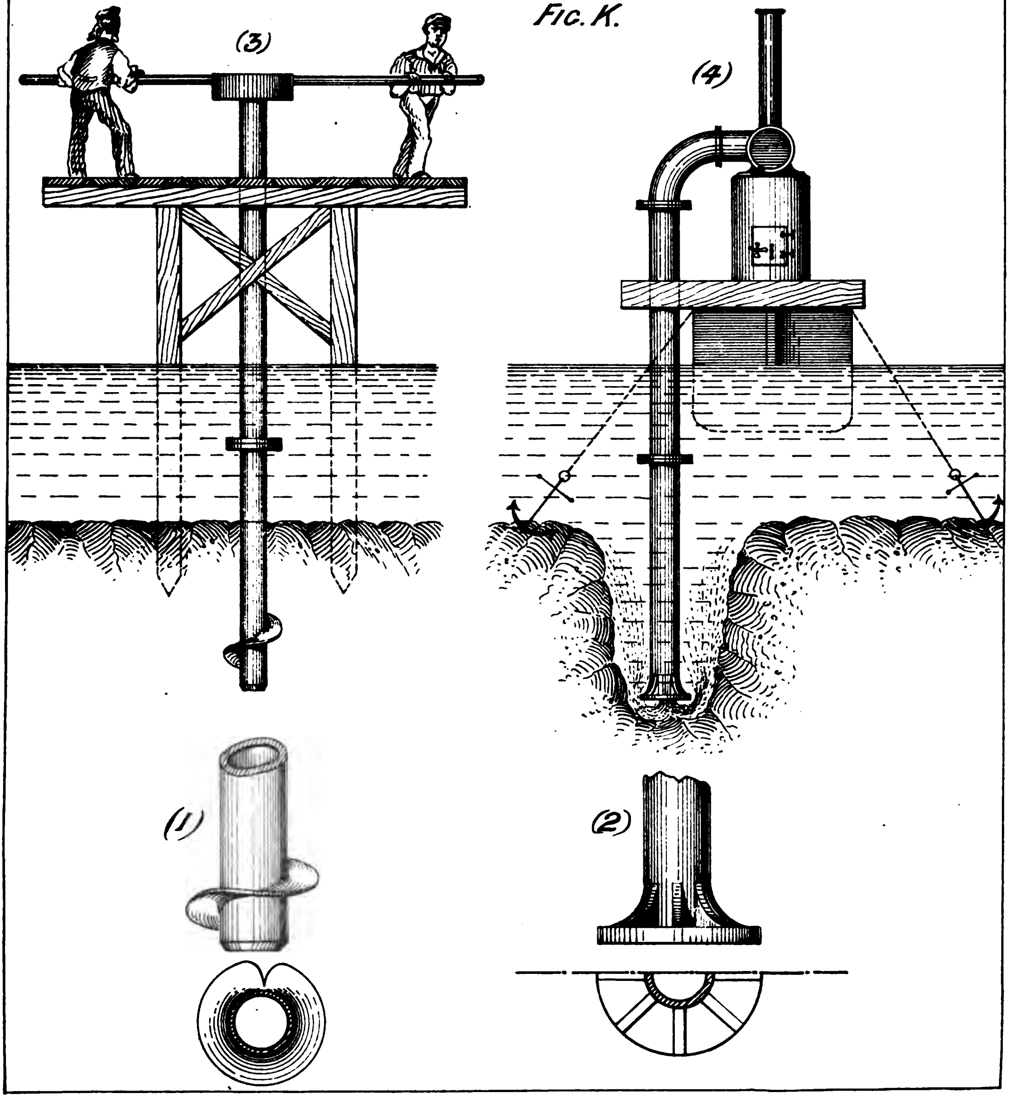
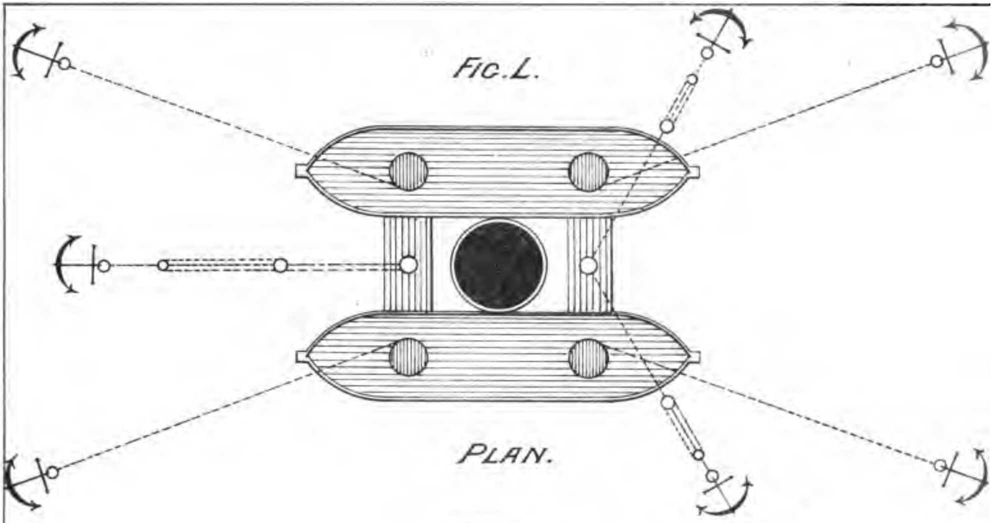
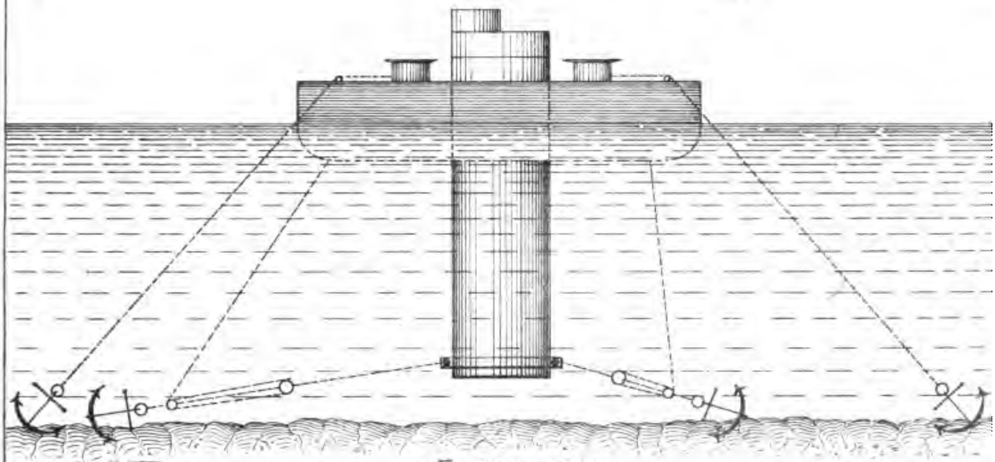


PLATE. 4

FIG. L.



PLAN.



ELEVATION.

FIG. M.

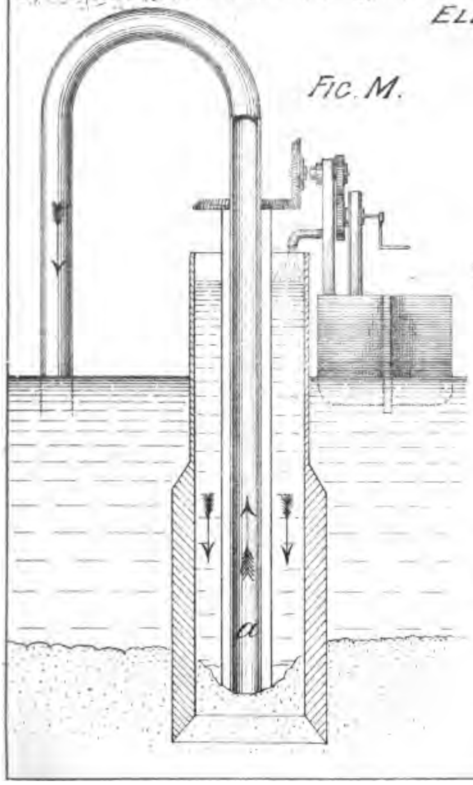


FIG. N.

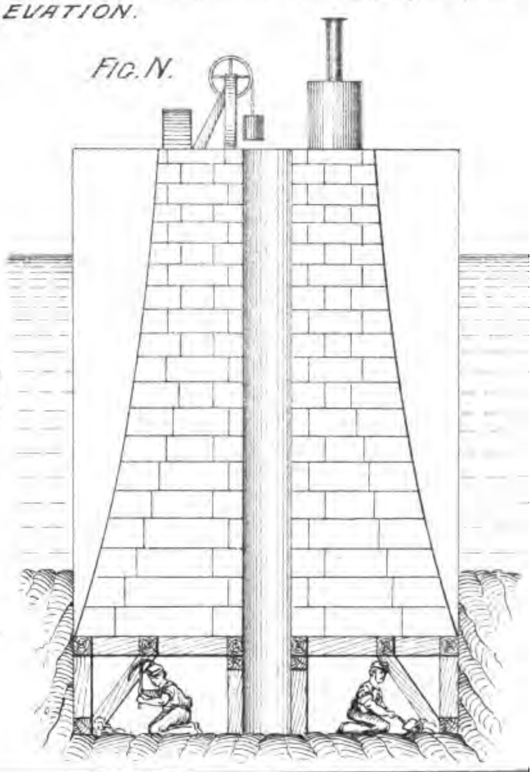
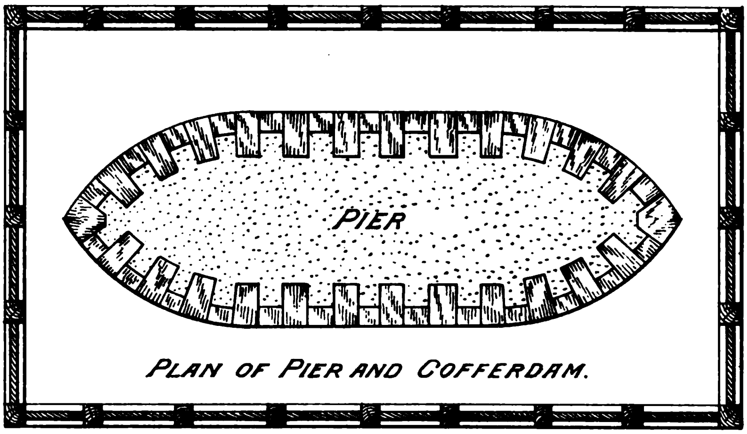


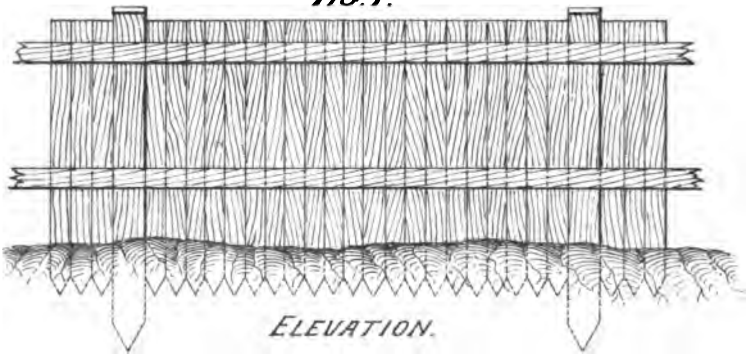
PLATE. 5.

FIG. O.

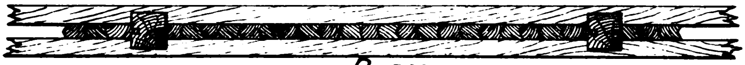


PLAN OF PIER AND COFFERDAM.

FIG. P.



ELEVATION.



PLAN.

FIG. Q.

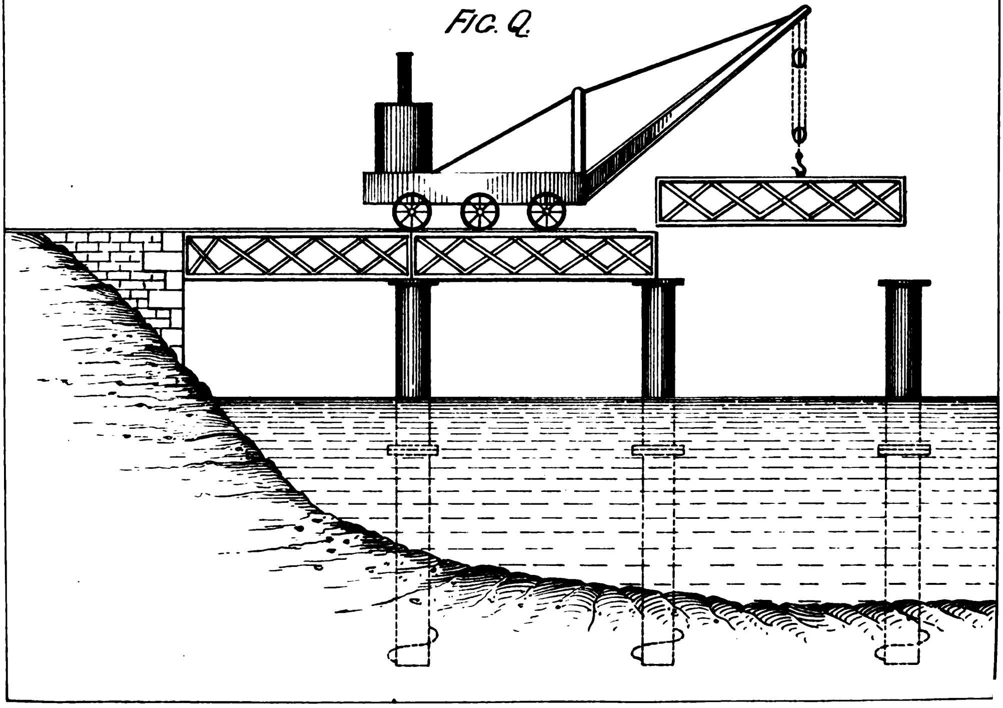


PLATE. 6.

FIG. R.

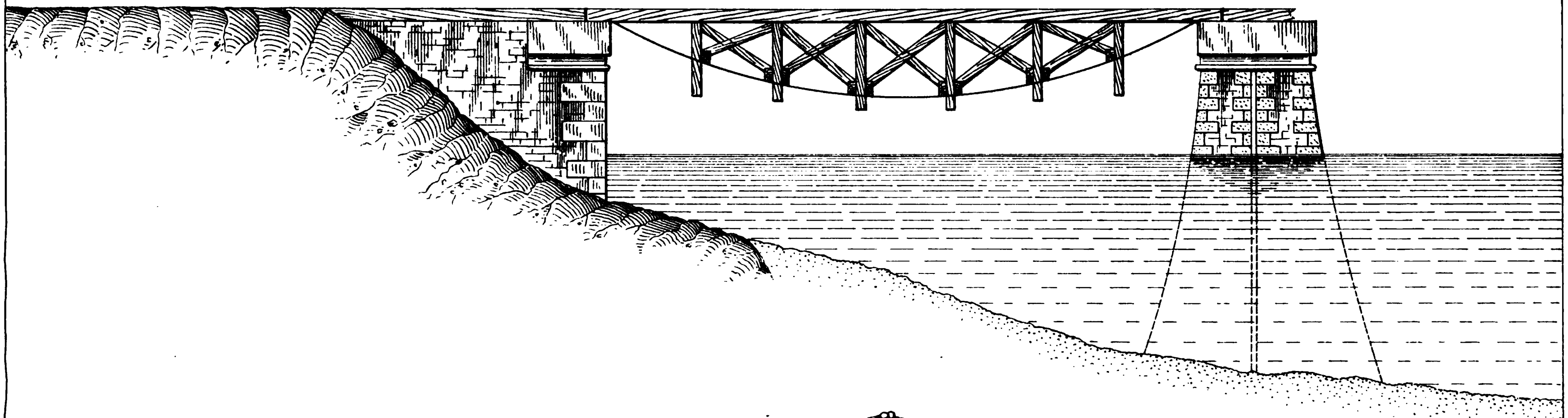


FIG. S.

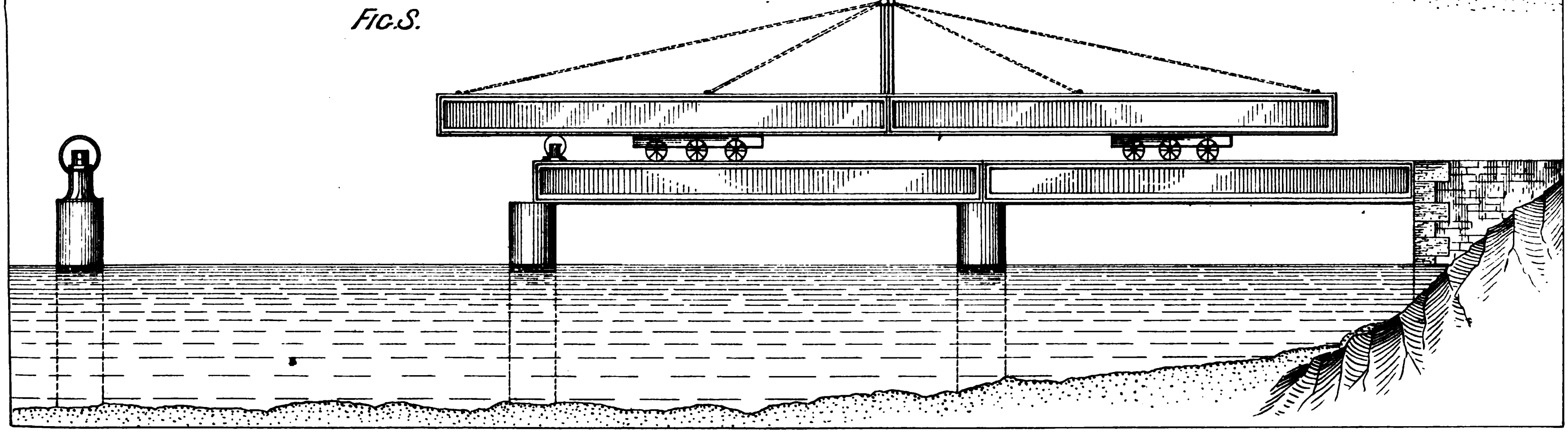
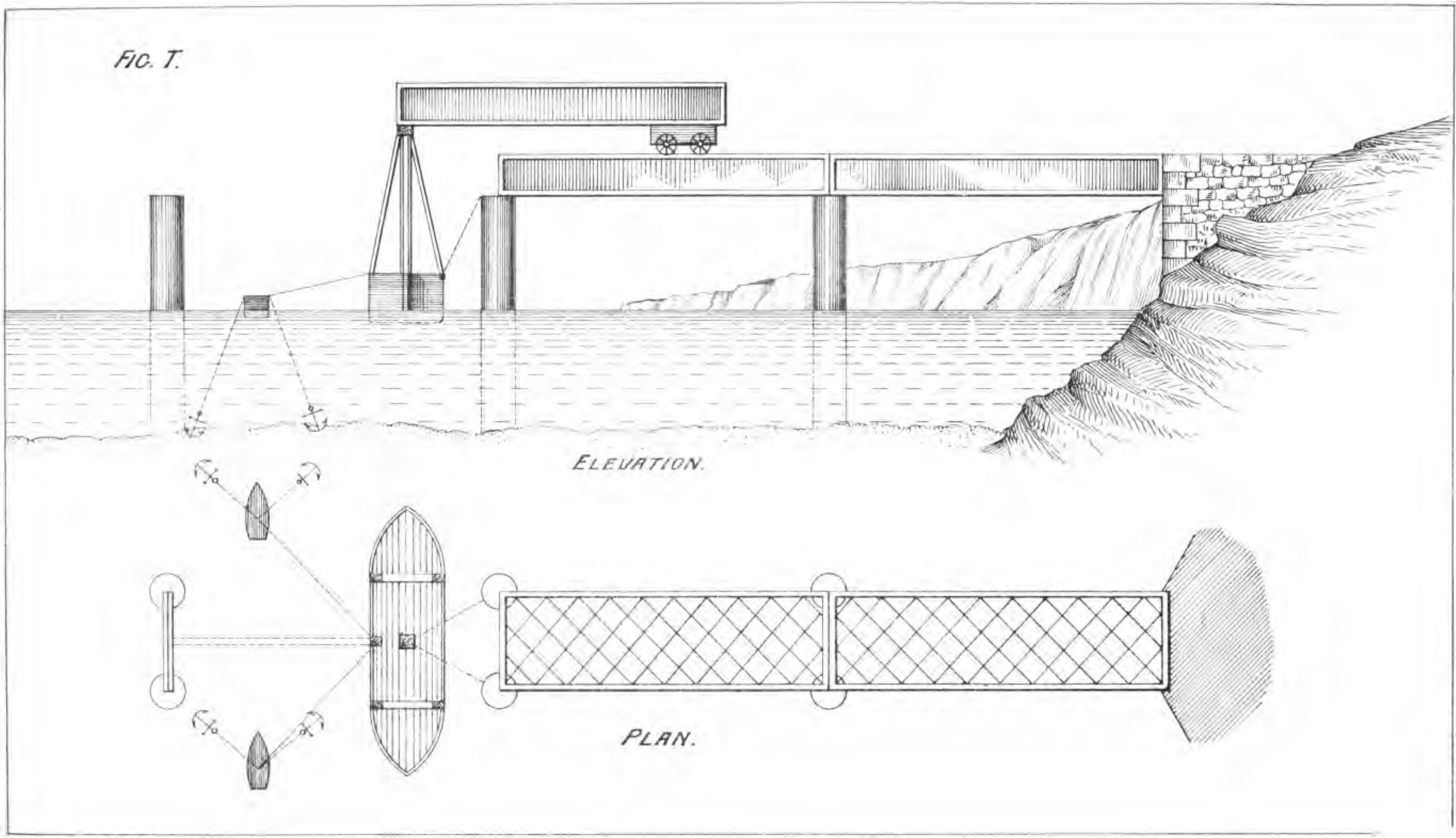


FIG. 7.



ELEVATION.

PLAN.

PLATE.

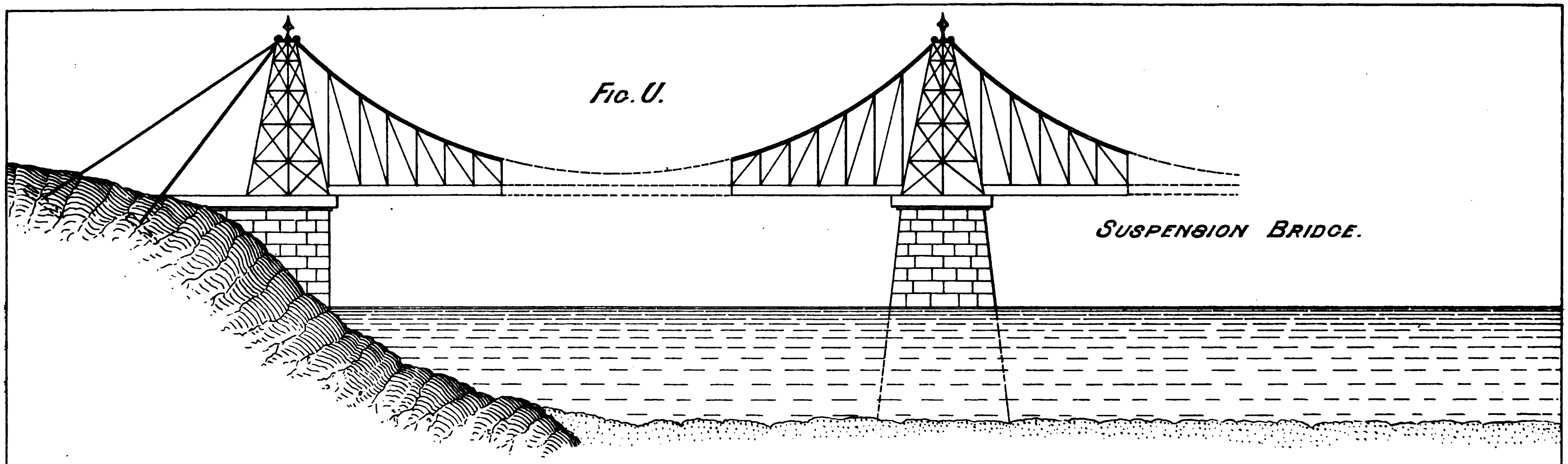


FIG. U.

SUSPENSION BRIDGE.

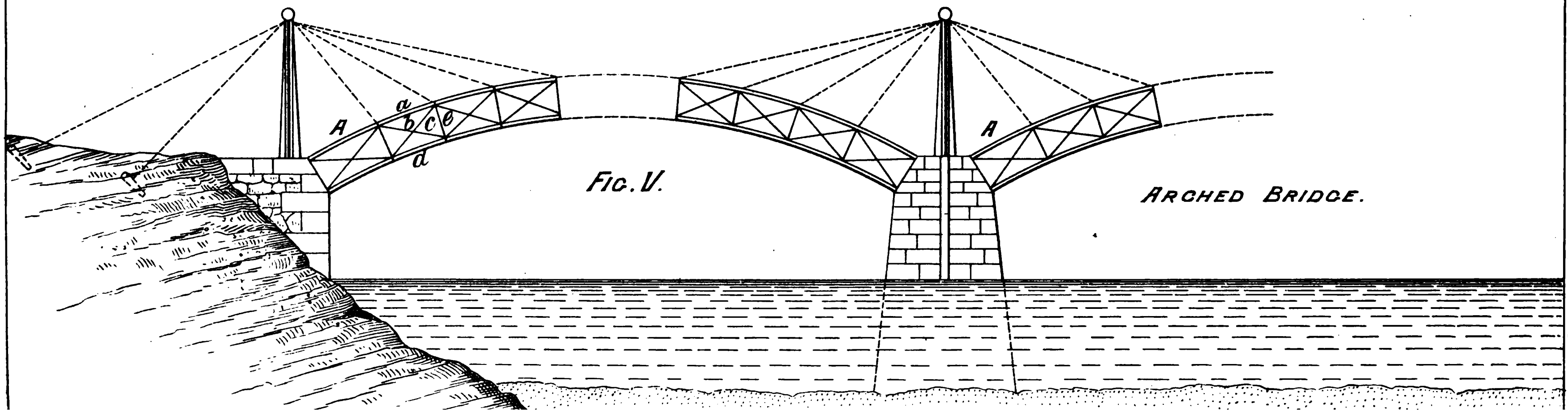


FIG. V.

ARCHED BRIDGE.

PLATE 9

FIG. W.

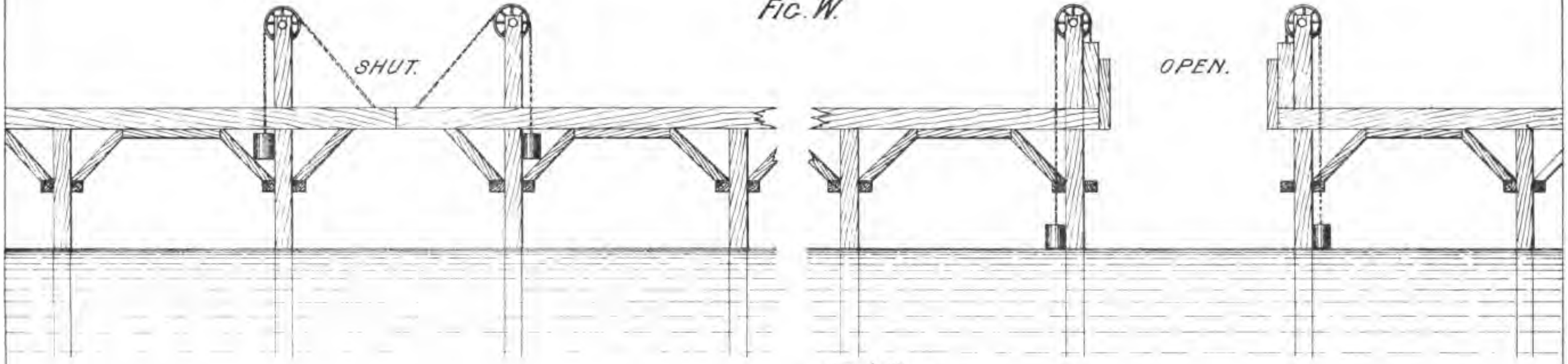


FIG. X.

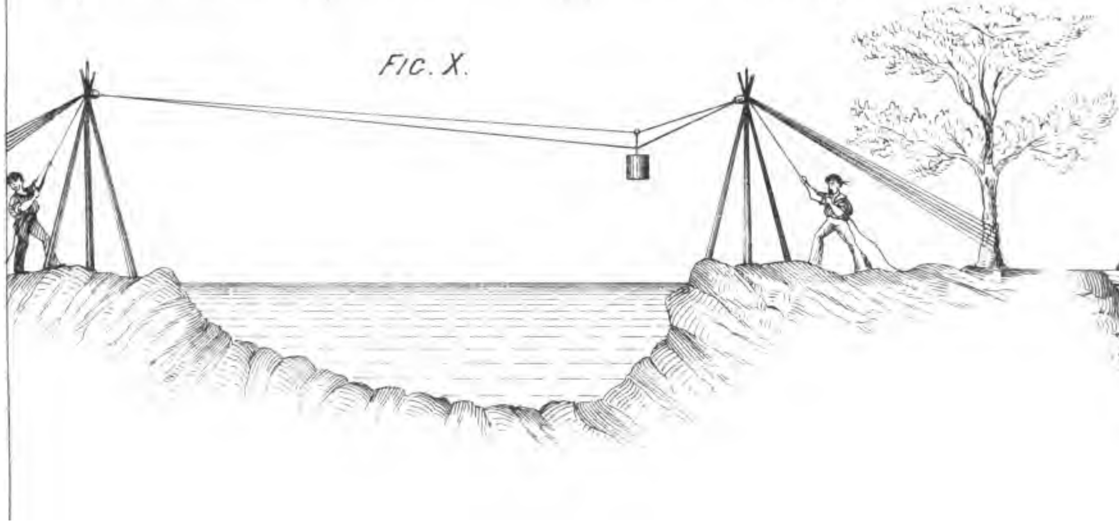
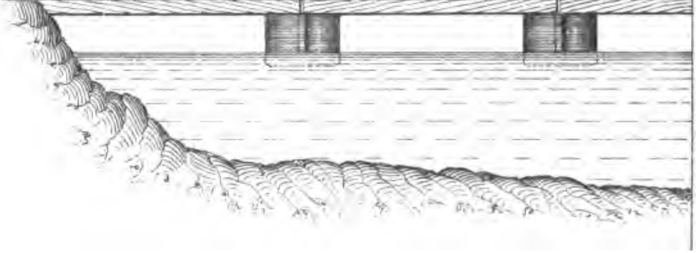


FIG. Y.



TEMPORARY EXPEDIENTS IN ERECTING

GIRDERS, ARCHES, AND ROOFS,

BEING EXTRACTS FROM LECTURES ON

PRACTICAL ENGINEERING CONSTRUCTION,

BY

G. H. PHIPPS, Esq., M.I.C.E.

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Design affected by means of erecting girders.

A VERY little consideration will show that the nature of the design for iron girders, &c., should be modified to a considerable extent by the conveniences at hand for their erection, and therefore, that designs very appropriate for one country or locality might be altogether unsuited for others. Some of the principal circumstances leading to a modification of design consist in the facility or difficulty of transporting the iron work to the locality where it is to be erected, to the plentiful or scanty supply of labour, and the timber or other material required for staging, scaffolding, &c.

In England, for instance, where timber is very plentiful, it is, we may say, somewhat lavishly used for the above purposes, leading frequently to the use of heavy fixed staging upon which to build up iron girders; when in situations commanding a less plentiful supply, other expedients for erecting the iron work would be resorted to.

Also, in England, where nearly every foreman (and even labourers) are fairly conversant with the framing of staging and scaffolding, and all necessary appliances are at hand in the shape of crabs, pulley blocks, screw and hydraulic jacks, and other necessary tackle, with blacksmiths, carpenters, and other artificers, always ready to make alterations or repairs, the case is altogether different to sending out work to some distant place (India for instance), where none or but few of the above appliances or conveniences are to be had. For such situations it is therefore evident, that a considerably larger amount of thought, on the details of contrivances for facilitating erection, may be advantageously expended, than would be the case at home, where everything is ready to our hand.

Different methods of erecting girders, &c.

In the erection of heavy iron girder work, the mode of proceeding may be classified under three separate heads, viz:—

1st, by erecting a substantial timber staging over the river or other place to be crossed, and framing up and riveting the various parts of the girder, &c., on the spot it is intended to occupy in the finished situation, a plan generally resorted to (when circumstances such as the free navigation of rivers, &c., will permit) in the case of works of considerable extent.

2nd, by framing up and riveting the girders on the ground, or some moderately elevated platform, adjacent laterally to the line of railway, and, when finished, elevating them by means of crabs, winches, and pulley tackles, or when large by hydraulic power, to the proper level, when they can be moved laterally to their intended situation on the piers.

3rd, by constructing the girders at some situation on the line of railway at one or both ends of the intended viaduct, and then hauling or pushing them over (to their intended situation) on to the tops of the piers, which are provided with rollers for this purpose.

This last plan may be subdivided into two, on the first of which the girder is moved from the place of its construction, over the whole length of the viaduct, and deposited permanently at the far end, each successive girder being brought up to the last fixed; while, on the other plan, the girder is first moved over the span nearest to the place of its construction, resting upon rollers, another girder being then attached to its after end, the two girders are shoved on together until covering over the first and second spans, when a third girder is attached to the rear, the whole pushed forward, and so on until all the spans are covered. This latter plan, although necessary in some cases (as afterwards detailed), evidently requires a much larger force to be applied in rolling the girders over than the first plan, since, on it, the length of girders to be moved over the piers keeps continually increasing, in proportion to the number of spans covered by the line of girders; whilst, on the first plan, there are never more than two lengths of girders to be moved at any one time.

I will explain the plans resorted to in a variety of cases for the fixing of girders of various spans and dimensions in their places.

Lifting girders up to 60 feet spans.

Figs. 1 and 2, *Plate* I, show the manner of dealing with girders of from 50 to 60 feet span, largely used about the railways in the neighbourhood of London, which are constructed chiefly on viaducts. The instance given in *Figs.* 1 and 2 is a girder of 60 feet span, for a bridge over a road; the bridge consisting of two main girders forming the parapets, which carry transverse girders, about 5 feet asunder, upon which the longitudinals and rails for two lines of railway are fixed.

Figs. 1 and 2 show a stout pole or mast, AA, some ten inches mean diameter, hooped with iron at top and bottom, and furnished at bottom with an iron pin for fixing into a slab of timber laid upon the ground, and at top with a bow or strap of iron with eyes at the ends, secured to the timber by a 1-inch bolt passing through them, for the convenience of attaching the block-tackle, consisting of two three-fold blocks, carrying a $\frac{3}{4}$-inch chain. The fall after leaving the upper block passes down to a snatch-block at the foot of the mast, and from thence to the crab-winch.

The mast is kept in place by chain guys, BB, *Figs.* 1 and 2, firmly secured near the ground, often, very conveniently, to portions of iron rails driven some three feet firmly into the ground. Such an arrangement as the above is quite equal to the raising of a girder of 10 tons weight, with a strain on the chain at the crab of $1\frac{1}{2}$ tons.

Lifting girders up to 60 feet span.

By placing the girder to be lifted in an angular position, CC, and the centre of the tackle over the line, DD, finally to be occupied by the girder, the girder may be lifted in the angular position, CC, until high enough, and then (a facility afforded by the single mast) slewed round and lowered into its proper position, DD.

When the girders exceed 10 tons in weight, the plan, *Plate* I, *Figs.* 3, 4, and 5, should be resorted to, where the girder is raised by pulley tackle at each end. Upright timbers, 12″ × 12″, marked EE, are erected upon sills, some four feet in advance of the bridge F, *Fig.* 5, and at a distance between them of about a couple of feet greater than the span of the bridge. These are carried up some 15 feet above the level of the under side of the girders when in position. Each upright supports one end of a crown piece, G, whose other end rests upon the top of a short upright, H, fixed upon the bridge abutments. The crown piece, G, serves to carry the lifting tackle, consisting of three-fold pulley blocks, reeved with ¾-inch chain, the fall of which is carried down over the snatch-block at the foot of the upright, and thence to the crab-winch.

While the girder is in process of being raised, and before it arrives at its highest position, the half timbers, II, are taken off, but ready to be placed in position immediately after, so as to receive the girder which is dropped upon them. The crown piece, G, being now supported temporarily, the upright timber, H, is to be removed, so as to admit of the girder being shifted laterally into its permanent situation.

Rolling girders into place.

I now propose entering upon a description of the mode of erecting the girders of bridges by the rolling process previously alluded to, and firstly on the plan forming the first part of the third general division of the subject, namely, by rolling the girders over the piers to their ultimate destination at the forward end of the series of openings to be covered. This plan has been very successfully followed in numerous cases in India, namely :—over the Palar River in 1858, the Cavery in 1860, the Chey-Air in 1862, the Chittranutty in 1867, the Pennair in 1868, and is still habitually practised on some of the lines in India. In most of the above examples the viaducts are of considerable length and with numerous spans, as, for instance, the Chey-Air viaduct consists of two portions separated by a short embankment; the first portion has 22 openings of 70 feet span from centre to centre of piers, and the second portion 16 similar openings.

The Pennair has 24, and the Chittranutty 40 similar openings.

Before entering upon a special description, in reference to the *Plates*, of the above method of removing the girders of bridges to their destination, a few general remarks will, perhaps, not be out of place as to its advantages over other methods.

This method of removing the girders of bridges into place is cheaper, safer, and more expeditious than the ordinary way of riveting the girders on staging. It is economical, since it saves the timber staging required for supporting and riveting up the work on the ordinary method. The cost of staging on lofty bridges becomes very considerable, while on the rolling system the altitude makes no difference. This method is also safer, as by it the danger is avoided to which lines of timber staging are subject (especially in India) from the numerous and rapid floods to which the rivers are subject, as well as from accidents by fire, and finally, it is more expeditious, since, by the ordinary method, the

Rolling girders into place.

erection of the girders is dependent on that of the staging, which (particularly if the piers are lofty) would only be put up for a couple of openings at one time, and then shifted forwards after the girders were in place; whilst, under the rolling system (provided there be a sufficient force of labourers) the fitting, riveting, and rolling of four, or even six, sets of girders behind each abutment can be proceeded with simultaneously.

All the above viaducts consisting of openings of equal span, one example will be sufficient for the whole, so far as the system of rolling over the girders is concerned. The Pennair Viaduct is the one now selected for explanation, referring to *Plate* II.

Under the above system of erection, it is requisite that the girders should be of such a length as to reach over two openings, and to the centre lines of the adjacent piers. In the present case, the girders (140 feet in length) were designed and constructed on the principles of continuous beams, and therefore, were strongest over the central pier under each girder. The separate portions of the girders were brought by a railway near the level of the ground to a position immediately behind the rear abutment of the viaduct, where the wagons were shunted into a siding close to the base of the embankment. The parts were then hauled up inclined planes, formed of rails, to the level of the embankment, where space enough was levelled off to admit of four sets of the continuous girders of 140 feet long being set up and worked upon in various stages of forwardness; what is called a set consisting of two girders of 140 feet long each.

As soon as one set was ready, preparations were made for launching; first, by lifting the girders some 18 inches by screw-jacks, in order to admit of the fixing of a line of rail laid upon its side, all along beneath each girder (*Fig.* 3, *Plate* II), which was done by riveting to the side of the rail narrow strips of plate iron, each long enough to allow of a pair of dog bolts passing through it, clear of the edges of the bottom flange of the girders. In order to ensure the forward extremities of the girders having support upon each pier in succession as the girders come up to them, rather before the tendency to tilt came into action, the rails just described were made to project 12 feet beyond the ends of the girders. While the girders were being thus prepared for rolling, three sets of rollers, of four in each set, were duly placed at distances of 70 feet asunder, one set on the embankment, one on the abutment, and one on the first pier. A pair of large double blocks were then fixed, the one A attached to the bracing frame at the end of the two girders, and the other B resting upon the top of the second pier, forward, and secured by means of a rope and tackle round the next forward pier.

A small pair of double blocks (*a* and *b*) were used to take up any slack caused by the stretching of the rope, and thus to keep the block (B) in its proper position.

A 6-inch Manilla rope was rove through the blocks A and B, one end being secured round one of the sheaves of the block A, and the other end, after taking a couple of turns round the crab band, was passed back to two men, who coiled it on the platform behind the crab as fast as it was wound in. Everything being now in readiness, a man was stationed at each pair of rollers to tighten up the rail dog bolts as they passed over, grease the roller axles, and attend to them generally. Twelve men were put to the crab, and the rolling commenced. When no delays occurred, the rate of rolling was about 1 foot per minute, but the time taken up in

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shifting the tackle, once for every two openings, and occasional delays from breaking of rails, rail straps, and loosening of dog bolts, did not exceed 420 feet in nine working hours.

When the girder had been rolled to its required position, three pairs of strong sleepers 1 ft. 6 in. by 1. ft. were fastened by dog bolts to the top flanges at the ends and centre, while under these, and resting upon the piers, were placed three pairs of stout traversing jacks, by means of which the girder was first lifted to take out the rollers, the rolling rails were dropped off, the girder traversed into the exact line, and lowered into place on its stone bed.

During the whole time occupied in rolling, lifting, and lowering, packing pieces and wedges were kept on the piers close under the girders, so that in the event ofthe breakage of a screw jack or roller, the greatest distance the girder could fall would not exceed ½ inch.

The principal point to be noticed in the above system of rolling girders into their places is the weight thrown upon the rollers at the worst position of the girders, namely, when just on the point of tilting, at which time the whole weight (38 tons) of the two girders, 140 feet in length, with their necessary bracing frames, is thrown upon four 8-inch rollers, or about 9½ tons each. Of course to bear this pressure, the rollers, spindles, and their bearings should be of a very substantial character, and the rail laid on its side beneath the girder, for bearing upon the rollers, should be carefully packed with hard wood wedges wherever there is a vacancy between it and the bottom of the girder, and this all the more particularly under the middle portion of the girder.

The economy stated to have been realized by the above system of rolling these girders into place is certainly very remarkable, the labour having only amounted to about £7 for each pair of girders per opening.

Bridge over Ganges at Cawnpore.

Another bridge may be referred to, designed by the late Mr. J. M. Heppel, and I believe now completed, for carrying the line of the Oude and Rohilcund Railway over the Ganges at Cawnpore, in which the girders were moved to their intended destination upon the piers by the rolling process.

This work is an important one, as having (like the high level bridge at Newcastle-upon-Tyne), not only to carry a railway on the top, but a common road also beneath. It consists of 23 river spans of 100 feet each, and 41 land spans of 41 feet.

The girders, 10 feet 8 inches in depth, are placed abreast of each other, so as to give a width of 12 feet outside the flanges, and are well braced together by the two platforms for carrying the respective roadways; the upper one being made 16 feet in width by sailing over the girders 3 feet on each side.

Mr. Heppel, although thoroughly aware of there being an absence of economy in any open work girders in which vertical members occur, yet (for reasons of the great convenience afforded by such members in respect of the two roadways with which he had to deal) elected to adopt them, and accordingly, the girders are framed up with vertical pillars placed at equal distances, between the top and bottom flanges, while the angular braces (with the exception of a few of the central bays in each girder) are placed so as to be entirely in tension, and the vertical pillars are all in compression.

The system of erection was to place a pair of girders of 110 feet in length, end to end with a second similar pair; to connect them sufficiently

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Bridge over Ganges at Cawnpore.

together so as to act temporarily as one continuous girder of 220 feet in length during the rolling operation, the whole being well braced transversely. The method of moving the girders (devised by Messrs. Campbell, the contractors for the bridge) was very ingenious, consisting of a worm wheel and screw apparatus (*Plates* III. and IV.), the worm-wheel being fixed upon the spindle of the roller, and the screw rotated by means of a ratchet lever. Ten of these rollers were placed upon each pier (5 under each girder), the ratchet levers being so connected together as to be acted upon all at once, as by the levers of a hand fire-engine. The lower flange of each girder had riveted to it a very stout T iron, the projecting limb of which bore upon the rollers, and thus the inconvenience of the irregular surface of the rivet heads was avoided,

Another very ingenious adaptation in Messrs. Campbell's apparatus, consisted in placing each of the rollers upon the head of a hydraulic ram, forced up with a certain and fixed pressure, so that, in the event of any slight irregularity of curvature occurring in the bottom of the girder, every roller would always bear its proper load. The above apparatus was set to work at Messrs. Campbell's works in October, 1870, the girders of their full lengths being operated upon, when they were moved a distance of 50 feet with great facility, at an average speed of 36 feet per hour. The weight (when equally distributed) upon each roller was about 7 tons, but this would be nearly doubled (or 14 tons) when the girders were about to tilt.

Bengal Railway Bridge over Gorai.

The next bridge to be described (*Plate* V.), is that over the Gorai River, on the Goalundo extension of the Eastern Bengal Railway.

This bridge consists of 7 openings of 185 feet each to the centres of the piers, and 9½ openings of 46 feet 3 inches each.

The height from the under side of the girders to the surface of the water, in the dry season, is about 35 feet, with depth of water of 40 feet, and speed of current of 3 miles an hour. In the rainy season there was a rise of 28 feet, with speed of current of nearly 5 miles an hour, and, at the same time, the river bed was scoured away to an increased depth of 24 feet, making the depth of water, in floods, upwards of 90 feet. Without entering upon the difficulties attending the foundations, &c., of a bridge in such a situation, as not within the scope of the present lecture, I will proceed at once to a description of the mode adopted for getting the girders into their intended positions, in reference to *Plate* V.

The principal peculiarity, in the present case, consisted in having to get the girders, of 185 feet long, from centre to centre of piers, into their places, the girders being too long (without very special adaptation) to allow of rolling them over the piers. The use made of the river for this purpose, shows an able adaptation by the engineer, Mr. Leslie. The girders were framed up upon the embankment at the eastern end of the bridge, a couple of them being very soon put into their places over the No. 7 span, which, being on dry land, was easily done by building up a staging, &c., within it, and so we may at once proceed to the No. 6 span, where the real difficulties began. The girders of the No. 7 span being in place, a temporary railway was laid between them, at a distance between centres of rails, of 7 feet 9 inches, resting upon longitudinal timbers, supported by transverse flooring girders placed 5 feet asunder. The girders for the No. 6 span were now to be taken over the railway, one at a time, until their outer ends rested upon the No. 6 pier, to do which, it was arranged for the outer end of each girder to be supported by a pontoon,

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afloat in the river, while the inner end was carried upon a powerful lorrie, capable of being moved on the above 7 feet 9 inch railway, upon rollers consisting of round iron, 10 feet long, and 3½ inches diameter. As soon as the *outer* end of a girder was moved, by warping the pontoon over the No 6 span, and when it was sufficiently over the forward pier it was lowered into its place by pumping water into the pontoon, and then the *inner* end of the girder resting upon the lorrie, was lowered by its means upon the after pier.

The manner of supporting the girder while in transit was very ingenious. For the forward end, carried by the pontoon, it was necessary to provide a support which could be varied in height, so as to suit the very variable height of the water in the river; this was done by means of two inclined timber struts (one on each side of the girder), wedged firmly against its upper flange, while their lower ends spread out to a distance of 30 feet, were planted upon a stout timber sill running fore and aft the pontoon, and strong enough to well distribute the strain over a considerable portion of its length. To allow of alterations in the length of the inclined struts, the length of each leg was made out in two pieces, separated by a space between, but kept asunder by means of a series of ratchet notches cut in them on each side, fitting into similar notches cut in two stout timber fishing pieces, well tightened up by means of iron straps and bolts, with hard wood wedges driven in between the square shoulders of the ratchets. The lorrie for carrying the after end of the girder was a very ingenious piece of mechanism, its objects being twofold, namely, to carry the weight of the after end of the girder while being drawn along the two lines of rails previously referred to on the iron rollers, and also either to enable the end of the *girder* to be raised or lowered, *acting from the lorrie as a base*, or, when the girder was lowered on to packings beneath, admitting of raising or lowering the *lorrie from the girder as a base*. This arrangement was necessary to allow of the removal of the rollers on the one hand, or of raising or lowering the girder on the other. The lorrie may be briefly described as consisting of two timber sills, lying immediately over the rails, on each of which are planted 12 inclined timber struts, all united together at top by means of an iron capping piece. The two capping pieces are united by means of a circular spindle or axle, 6 inches in diameter, passing through them, on which two narrow box girders, 15 feet long, are transfixed, at a distance of 2 feet 9 inches from centre to centre. These box girders are for the purpose of supporting two lines of screwed suspension bolts, of 1½ inch diameter, 10 bolts in each line, their lower ends passing through brass nuts fixed beneath the top flange of the girder to be supported.

The upper ends of the suspension bolts are attached to an equal number of worm wheels, the bosses of which are fitted, and capable of turning in sockets formed in the box girders. The worm wheels are actuated by a series of screws or worms, so fixed upon a horizontal spindle running parallel with the box girders, as that every screw works into two worm wheels. Thus, by this arrangement, all the suspending screw-bolts are rotated simultaneously, and therefore, all take an equal strain. By turning them in one direction *the main girder is lifted*, and if this latter be blocked up, and the bolts turned in the contrary direction, *the lorrie may be lifted*. In reference to the weight to be supported by the pontoon and the lorrie, viz., 65 tons on the former, and, at one time, on the latter, including the lorrie, rollers, &c., 90 tons, we may well see what great

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strength and precautions were necessary. Taking the inclined timber struts on the pontoon, we have 43 feet of length, by a cross section of 1 foot 6 inches by 1 foot 4 inches, each bearing a compressive strain of about 34 tons; there are, it is true, appliances, in one direction, calculated to reduce the tendency to flexure, and in the other direction the legs are stiffened by the timber fishing pieces, but still, 34 tons, in such a situation, is a very severe test indeed. Another consideration has reference to the longitudinal stability of the pontoon, since a weight of 65 tons, at an elevation above the water of 43 feet, must require a very careful adjustment over the centre of gravity of displacement of the pontoon, to avoid disturbance of its horizontal position in the water, and consequent twisting of the girder. Also, as regards the management of the pontoon, it was necessary to confine it in its motion across the river, as nearly as possible, to a position at right angles to the intended line of railway. This was effected by employing two parallel lines to pay out with one fast to each cylinder of the pier (a distance of 37 feet 6 inches from centre to centre), both lines being paid out simultaneously from a single bollard; and similarly, by using two parallel hauling lines both wound on the barrel of the same winch, so that both lines were equally hauled upon. The winch was placed in a barge secured to the off, or western side of the pier on which the girder was to be landed. By these lines the pontoon was kept very nearly at right angles to the intended line. To avoid straining the girder or after-lorrie (which admitted of no horizontal swiveling motion), it was necessary for the pontoon to be moved across from pier to pier in a straight line. To facilitate this object, two barges were moored in the line of the centre of the span, one at a distance of 40 fathoms above the bridge, and the other at an equal distance below. Warps, 7 inches in diameter, made fast to these barges, were led to capstans fixed on the bow and stern of the pontoon. Auxiliary warps were also laid between the barges and pontoons, and adjusted by luff tackles. By heaving uniformly on these warps until the pontoon reached the middle of the span, and then by slacking out, the motion of the pontoon was confined, within a few inches, to a straight line. The auxiliary warps were used in case of any sudden alteration in the direction or strength of the wind during the process of launching, which, acting upon the superficial area of the girder, might have brought too much strain on the single warp.

It will be seen that the chief difference between this case and the Pennair (independently of the pontoon) consists in making good each span from the starting point, and making use of the completed spans for transporting the girders for the spans beyond.

Bridge over Grand River, Mauritius.

The two remaining examples of bridges, with girders placed in position by the system of rolling, are the bridges over the Grand River in the Mauritius, and one erected at Fribourg, in Switzerland, over the Sarine.

There is a certain similarity in these two cases, as both bridges were erected under the system forming the 2nd subdivision of the 3rd general division of the manner of erecting girders, previously referred to at page 30; namely, when, as span after span is crossed by the girders rolled over, other girders are (so to speak) fed on at the rear, and thus a continually increasing length of bridge has to be rolled forward as each additional length of girders is applied. This was not, however, the whole of the peculiarity of these designs, since, besides the overhang of one whole span (over any given pier), the piers were intended to be erected by using this

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Bridge over Grand River, Mauritius.

overhanging portion as a cantilever, from whence to lower down the ironwork of the pier about to be constructed. In the Mauritius Bridge, (*Plates* VI., VIA. and VIB.), however, this plan of erecting the piers had to be given up, in consequence of the great delay in the delivery of the girders upon the ground, rendering it obligatory to proceed with the piers so as to have them ready in time. The Mauritius Bridge consists of four spans of 116 feet each in the clear of the piers, the rails lying at a level 134 feet above the valley, and constituting a single line of the 4 feet 8 inches gauge. The permanent way is carried by cross beams resting upon the top flanges of the main girders, which are parallel throughout, and consist of top and bottom flanges, 2 feet wide by 2 inches thick, attached by stout angle irons to the middle rib, which is of solid boiler plate, their extreme depth being 8 feet.

Prior to launching the two girders to the length of 252 feet, and weighing, with their cross-bracing and chain-trussing, 190 tons, were put together in a gullet of the cutting, immediately contiguous to one of the abutments, at first, with the above weight supported upon six rollers, giving a weight upon each roller of 32 tons; afterwards the number of rollers was increased to 14, which then reduced the weight upon each to 13½ tons, and at one period of the launch, one pair of rollers had to bear the weight of 95 feet in length of the girders, &c., overhanging, equivalent to about double that weight, or 76 tons on each roller. The consequence of these enormous pressures upon the rollers (and upon what is called, a 'keel plate,' 3½ inches × 1 inch, fixed by counter-sunk bolts all along the bottom of the girders) was an immense inconvenience, from the extending or rolling out of the keel plates, a length of 4 feet of which in one instance was elongated as much as 2 inches.

One of the great difficulties arose from the irregularity of the under side of the lower flange of the girder, from the projection of the cover and strengthening plates, and also, in some measure, from the camber given to the girders.

With the dimensions given of the propelling levers and rollers, and assuming the power of the double purchase crabs to be as 98 to 1, with 9 men, each working with a force of 30 lbs., the strain on the ropes from the crabs to the levers would be 11½ tons, which, into the ratio of the levers to the rollers, 30 to 1, and an addition of 9 tons for the effect of the pulley tackle applied to the ends of the girders, would give a total of 11½ × 30 + 9 = 354 tons, an amount of force out of all proportion to the weight of the girders moved, namely, 190 tons.

A complete failure in launching, as was to be expected, being the result of the above arrangements, it was determined to alter the system by dispensing with the rollers, and arranging for the girders to be simply slid along upon a railway laid beneath. The girders were supported upon cross balks, 9 inches × 9 inches, placed 12 feet asunder, and furnished (where resting upon the rails beneath) with iron plates, to slide, or skid upon them. By this arrangement, the plate and rails being well greased, and striking the ends of the skids with sledge hammers, the process of launching was successfully performed. With a pulley arrangement, substituted for the ratchet levers, a force of 86 tons was all that was required, and this not merely to move the portion of girders on the land, but also the whole length over the five spans. That part of the weight which rested upon the piers, being supported upon a system of rollers 5 inches in diameter, running upon smooth and well bedded cast

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iron plates, no doubt occasioned but little resistance as compared with the portion of the girders on land.

There is but little doubt that the chief cause of resistance on the first attempt to launch, arose from the inadequacy of the keel plates to bear the strain, causing them to buckle up and elongate, and thus most materially to interfere with the advance of the girders.

Bridge over Sarine, Fribourg.

As of the same class of operations with the Mauritius Bridge, I now proceed to the bridge over the Sarine, at Fribourg, in Switzerland, *Plate* VII. It consists of 7 spans of 160 feet each, of trellis girders, fixed at an altitude (at the highest points above the valley to the under side of the girders) of 262 feet 6 inches, and carries a portion of the line from Lausanne to Fribourg, a double line of railway. Similarly to the intention with regard to the Mauritius Bridge, the bridge was designed, *and executed*, so as to enable the iron-work for the piers to be brought by railway and lowered down to its intended destination. The piers, to a depth of 144 feet below the girders, consist entirely of cast iron, disposed as 12 columns braced together in each pier.

The girders for the 1st and second spans, taken in connection with the chain bracing, were so calculated as to have sufficient strength to bear their own weight, together with all necessary adjuncts when on the balance over the piers. As soon as the first pier was completed, four rollers were fixed upon it to receive the overhanging extremities of the girders in process of being hauled over, and to allow of their further advance.

Since the piers, from their great height, were liable to be deflected by a lateral force, they were tied back to the abutment (and to one another as the work advanced), by means of cables, but of less and less strength as they became more remote from the abutment.

In this case the girders, &c., are stated to have been supported on each pier during the progress of launching, on 4 rollers of 31½ inches diameter, each roller with axle, 6½ inches diameter, running in plummer blocks.

With rollers so large in diameter, there is little doubt that the resistance of the bridge to motion would be much reduced from what happened in the case of the Mauritius Bridge.

It is stated that the time taken in hauling the bridge over one span of 160 feet was six working hours, with only 16 men employed.

If we take the weight moved at any one time to be equal to two spans, or, say, 340 tons, and a pulling force of 5 tons were applied, this would be equal to the $\frac{1}{68}$ part of the weight.

I wish to observe that nearly all the examples of bridges referred to are taken from able papers read at the Institution of Civil Engineers, all of which are fully recorded in their public transactions, and to these I beg to refer gentlemen who may wish to go further into all their minute details.

LIFTING GIRDERS INTO PLACE.

Having referred to several bridges erected under the system of rolling the girders longitudinally into their places, I now propose giving some particulars of the method employed upon the Great Indian Peninsular Railway in getting into place, by a different process, some long girders for the reconstruction of a portion of the previous arched structure which had given way.

New Mhowke-Mullee Viaduct.

The bridge referred to (*Plate* VIII.), designed by Mr. G. Berkley, is called the "New Mhowke-Mullee Viaduct," and consists of 4 Warren girders (one under each rail), of a double line of railway, of 202 feet

LIFTING GIRDERS INTO PLACE.

New Mhowke Mullee Viaduct.

span, by 20 feet deep to centres of eyes, and 150 feet from the rail to the ground. Each of the girders weighed about 112 tons. The girders were bolted fast upon the central pier, but left free at the abutments, where they were laid upon a frame work of boiler plate, 1 foot deep, upon which to slide.

The various component parts of the girders were brought and put together upon a platform, some 60 feet above the lowest point of the valley; another platform, about 18 feet above the first, being also constructed for the convenience of putting together the parts of the upper boom of the girder, and it was from this last platform the girder had to be lifted to its destination, a height of about 64 feet.

All this being premised, we may next consider the main points which have to be attended to in the raising, and fixing in place, heavy girders of the above kind. These may be very simply stated as consisting of—1st, an adequate power to lift the weight, and 2nd, since the length of the girders must necessarily exceed the clear space between the masonry of the pier and abutment, the girder must be lifted so far laterally from the centre of the viaduct as will clear the masonry, and consequently, the means must be provided for traversing the girder laterally (after being raised to the proper height) to its permanent position.

It may also be added, that whatever the means resorted to for the raising of these great weights, the utmost precaution should be taken to guard against the effects of a fall in the event of the breakage of the lifting tackle, and this can only be done by arrangements for reducing the distance fallen through to the smallest possible quantity. With these prefatory remarks we will now proceed to describe the nature of the staging employed in the above bridge, although, owing to the circumstance of the engineers having a considerable quantity of iron columns at hand, these were used, whereas in general the engineer would have to use timber. Little difficulty, however, would exist in adopting wooden framing instead of iron with any one who was acquainted with the present operations.

The first operation was to erect a platform, of about 32 feet in width, the whole length of the viaduct, at a height of about 60 feet above the lowest point of the valley. This consisted of a flooring of plank, resting upon four longitudinal timbers, which were carried by a pair of transverse timbers placed one on each side of a row of three iron columns. There were 14 such rows of these columns, placed at a distance of 33 feet 1 inch from centre to centre. It was to the level of the above platform the materials for the girders were first brought and deposited.

Another platform of similar width to the above was then constructed for the length of one of the spans, and about 18 feet above the former. It was carried on the tops of 18 of the iron columns, forming a continuation of the columns below, its object being to facilitate the construction of the upper boom of the warren girder, and the suspending to it of the angular pieces and tension links below. For the support of the travelling lorrie and lifting apparatus, a framework had to be constructed at an altitude of 75 feet (at the pier) above the last described platform.

Over the pier the framework consisted of three main timbers, carrying the rails for the lorrie, running transversely to the viaduct, and supported by upright timbers (with raking shores) planted partly upon the masonry and partly upon the top of one of the cast iron columns carried

LIFTING GIRDERS INTO PLACE.

New Mhowke-Mullee Viaduct.

up from the ground, and passing through the first and second platforms. Over the abutment the only difference in the framework consisted in there being only two (instead of three) main transverse timbers for the passage of the lorrie—and in upright timbers planted on the masonry—and that *two* (instead of the one only) of the cast iron colums were carried up.

The apparatus for lifting the girders consisted of a lorrie composed of wrought iron frames, on which was fixed a hydraulic press cylinder, with a 6-inch ram, and capable of making a 2 feet stroke.

The ram carried a cross-head, to each end of which was attached a chain composed of suspension bars, 12 feet long and 7 in. × $\frac{5}{8}$ in. section, with two such bars in each chain. There were consequently four bars of 7 in. × $\frac{5}{8}$ = 17½ square inches of sectional area to each ram. The suspension chains were attached to the end of each girder by a cross bar and stout links keyed on to the last pier. In order to provide for the repetition of the strokes of the ram (2 feet in length) the suspension links were perforated with 3-inch circular holes, 2 feet from centre to centre, into which stopper pins were passed at the end of each stroke, the pins being passed at the same time through 3-inch holes formed in the sides of a cast iron frame on each side of the hydraulic ram through which the suspension bars passed. Thus, at the end of every stroke the stopper pin was inserted to take the load off the ram, when (the connection with the ram cross head being taken off) the ram could be lowered, the cross head connected 2 feet lower down, the stopper pin taken out, and another 2 feet lift made with the girder.

The total sectional area of the lifting chains, after deducting the 3 inch stopper holes, was 8 times 7 in. × $\frac{5}{8}$ in. = 35 in. — 15 sq. in. taken out = 20·0 in., thus giving a strain with the 112 ton load of 5·6 tons on the square inch.

With 15 men at the pumps (1 in. diameter, 4 in. stroke), and working at 25 strokes per minute, the speed of lifting was about 12 feet per hour, which speed (with some unimportant exceptions) was well maintained throughout.

A point which strikes us in the above arrangements is the apparently large proportion taken out of the suspending links by the 3-inch stopper holes, out of bars 7 inches wide, as there is much question whether the remaining sectional area of the iron could be relied upon to the same extent as if it were the uniform section of a plane bar.

It appears also that in cases similar to the above, some method of following up the girder, during its ascent, with a support applied at very short intervals, would be very desirable, as reducing the injurious consequences arising from accidental breakage of the tackle employed.

Although in the above bridge the strain per square inch upon the iron of the suspending chains was only 5·6 tons, where in some cases (the lifting of the Britannia Bridge for instance) 8·3 tons have been applied, I am still of opinion that some precaution should be taken in the event of a breakage. The first idea which occurs is to apply extra chains (not doing any work ordinarily) to come into action in the event of a breakage of the *acting* chains; but the objection to this is, that such chains being slack (in their ordinary condition), the strain would come upon them with a jerk. To meet this objection they might be kept taut by passing over a ram of subsidiary hydraulic press, so constructed as to move upwards at the same rate as the *acting ram*, but only subjected to a sufficient pressure to keep the chains taut,

LIFTING GIRDERS INTO PLACE.

Britannia Bridge.

Having now entered at considerable length upon various methods of putting the girders of bridges of *ordinary* span into their places, some reference may be made to such *extraordinary* cases as the "Conway" and "Britannia Bridges," both (and particularly the latter) works of such magnitude as quite to dwarf most ordinary projects, and (what should never be forgotten) that these bridges constituted examples which, however much they may have been improved upon in special design since then, nevertheless gave such an impulse to the science of bridge building, that, whereas before their time bridges beyond 80 up to 100 feet span required the most attentive consideration of able engineers, the same things, and even much larger, are now put out of hand readily by our youngest engineers.

Without going too much into detail on these well known structures, it may be stated generally that the Britannia Bridge consists of four spans, two in the middle over the Menai Straits of 460 feet each, and two land openings of 230 feet each at the ends, the clear distance from high water to the under side of the tubes being 100 feet. The total weight of one large tube as completed was 1587 tons, and of one short or land tube 630 tons. Timber scaffoldings of enormous magnitude were erected upon which to construct the *land* tubes, each scaffold having to sustain a weight of about 1200 tons. On the Anglesey side of the Straits this staging contained no less than 76,363 cubic feet of timber. It constituted a platform 230 feet long by 78 feet wide, supported upon 14 rows of upright timbers about 15 inches square, placed 18 feet apart, each row containing 6 timbers 12 feet apart. The weight to be supported (1200 tons) was however carried exclusively by the 4 inner uprights in each row, which accordingly had to bear an average weight of 20 tons each, but in some instances a weight of 175 tons was placed upon 4 supports only. Of course in this framework an enormous quantity of longitudinal and transverse timbers, and of braces and diagonal struts were introduced.

The scaffolding for the Carnarvon side (averaging only about 60 feet in height) only contained 4200 cubic feet of timber.

In floating each tube from the shore to its intended position the weight was borne by 8 pontoons, each 98 feet long, 25 feet wide, by 8 feet deep, and capable of supporting 460 tons when fully loaded, or 57 tons per foot of displacement.

The floating into place of these pontoons, with their enormous load, was a work involving far too many details to be made intelligible on the present occasion; suffice it to say, that considering the responsibilities to the engineers, the risks to be run—and actually encountered—and the consequences in the event of a failure, it is impossible to imagine a more exciting occasion than the floating presented; and nothing is more surprising than that all the four tubes should have been safely deposited in their intended berths.

Arrived at its proper situation, and once deposited in the chase left in the piers for its reception, the process of raising each tube was at once commenced. The raising was performed by means of three hydraulic presses, two of which were fixed on iron beams in the central pier, above the level of the tops of the tubes, and the remaining one on the landward pier. The pair of hydraulic rams on the central pier, and the single ram upon the landward pier, both carried enormous cross heads, each of which supported the upper extremities of two main lifting

LIFTING GIRDERS INTO PLACE.

Britannia Bridge.

chains, the lower ends of which were attached to the tube to be lifted by passing through a framework of cast iron fixed in the tube, for the purpose of keeping it in shape, as well as of affording a convenient manner of connecting to the chains.

The weight to be dealt with in one main tube was 2065 tons. The three hydraulic presses used were all of 6 feet stroke; the single press on the landward pier 20 inches diameter, and each of the two on the central pier 17 inches diameter. When the presses were fully loaded, the weight was not equal at the two extremities of the tube, being, on the single press, 1144 tons, and on the double one 921 tons, total 2065 tons; thus, the strain per square inch was:—

On each ram of the double press,

17 inches diameter, ...

$$\frac{460\cdot5 \text{ tons}}{227 \text{ area}} = 2\cdot03 \text{ tons per sq. in.}$$

On the single ram, 20 inches diameter ... ...

$$\frac{1144 \text{ tons}}{314\cdot16 \text{ area}} = 3\cdot64 \text{ tons per sq. in.}$$

To bear the above weights the aggregate sectional area of the chains employed was 276 square inches, consisting of assemblages of links of eight and nine links alternately, all 7 inches wide, the eight plates being 1¼ inches thick, and the nine plates 1 $\frac{1}{10}$ inches thick. Thus, the *average* strain on the iron bars was 7½ tons on the square inch, but the *greatest* strain 8⅓ tons. This strain was evidently too great, as the iron at the pin holes, where bearing upon the pins, was visibly upset (thickened) by it.

Some of the links, tested up to 15⅓ tons, also showed the above effect, and the elongation of a length of 3 feet under the strain was ·225 inch, with permanent extension of ·175 inch. Each link was 6 feet in length to the centres of the eyes, and was enlarged from the body of the bar (the 7-inch part) by two rectangular shoulders 1⅛ inch each full (bringing the width to 11¾ inches) for the purpose of "stoppering" on the termination of each 6-feet lift. For this purpose (of stoppering) two sets of clamps were employed, one set placed on the cross-head and rising with it, was used for lifting the chain and tube direct; the under set was fixed on the cast iron girders supporting the press, and was used for securing the chain at the end of each lift while the ram was lowered and the upper set of links removed. The wrought iron clamping chocks were slotted to fit closely to the square shoulders on the links; they were drawn close together, in a parallel action, by means of right and left handed screws, worked simultaneously and easily by one man, by means of gearing and a winch.

The speed of raising the tubes was 6 feet per day, but the time actually occupied on each such lift only 45 minutes, so that, so far as actual speed was concerned, the whole 100 feet might have been done in one day; but there were many things to be done, and not the least important was the following up, beneath the ends of the tube, with brickwork masonry in cement as far as the tubes rose—a precaution on which the engineer (Mr. Stephenson) always insisted.

We may conclude this brief notice of the gigantic work of the Britannia Bridge by remarking upon the wonderful success which attended the whole of the operations connected with it, particularly in the floating of the tubes, in a tideway of great speed, and with but a very short time of slack water; indeed the possibility of casualties fraught with such tremendous consequences must have required the greatest amount of nerve and determination on the part of all concerned in the practical operations.

ERECTING IRON ARCHED BRIDGES.

I now pass to the consideration of the manner of erecting arched bridges of iron.

It will be at once apparent what great facilities are offered in the erection of iron arched bridges, over those of stone or brick, particularly in the case of very large spans. The quantity and strength of the timber employed in the centering and supports for it, of the latter class of arches, requires to be enormously great, in order to prevent distortion by the almost unavoidable unequal loading in the process of erection. In arches of iron, the quantity of scaffolding required for their erection is very much smaller than for arches of masonry or brickwork, since to begin with, the metallic arches are much lighter, and, next, being generally brought to the ground in sections of considerable length, only requiring their principal supports at the extremities, it is clear by how much the quantity of scaffolding is thereby reduced.

In a bridge of 150 feet span, for instance, there would be no difficulty in making up each separate section of a rib to the length of 50 feet, requiring three such portions, and consequently, only four points of support. Such supports, together with the trusses they carry, would only require to be of a very light character, so light, indeed, that the dimensions of their timbers would have to be determined upon from a variety of reasons, other than for their requisite bearing power.

With a malleable iron arch of 150 feet span, and 15 feet rise, one rib would weigh about 15 tons, one third of which, or 5 tons, would be the weight of a section to be lifted at one time.

The simplest way of erecting a bridge of this kind, is by erecting a staging supported either upon upright timbers, or sills resting on the ground (when the bridge is on land), or upon piles, when over water. A single row of four piles, in the elevational view, with five piles in each row, transversely, would be amply sufficient for a bridge of 150 feet span, for carrying two lines of railway. The two outside piles in each row may be carried up, some 12 or 15 feet above the intended level of the line of rails, carrying longitudinal timbers, forming a "gantry" for a "traveller" extending quite across the bridge. The traveller is a most convenient apparatus for this description of work, governing as it does, the whole area included within its longitudinal and transverse limits of motion. And whether the bridge be situated on dry land, or over water, it serves to pick up and elevate materials from trucks or wagons, on the one hand, or from lighters or boats on the other.

In placing the ribs of iron arches in their intended situations, two methods have been resorted to, the more usual one being to complete each rib upon the timber supports below, leaving the masonry or brick-work on the piers or abutments to be made good to the skewbacks of the ribs so placed, and this was the method practised in the new Blackfriars Bridge. The other method was made use of at the Victoria Railway Bridge, over the Thames, at Chelsea, where the ends of the arch ribs are made semicircular, and rest in cast-iron sockets, made accurately to fit the ends of the ribs, these socket-pieces being, in their turn, fitted into other sockets of a rectangular shape, built into the masonry, in which

from end to end of the building, and so to apply itself seriatim to each principal in its turn. The frame is contrived to allow of the principal being lodged upon it at a distance of about 1 foot from its hinder vertical face, the tie-bar being supported on chocks on the upper side of the traveller, while the principal rafters are placed upon projecting angle-iron brackets bolted to the upright timbers of the frame. Thus supported, with convenience afforded for plank scaffolding, the attachment of the struts and braces becomes simple and easy. It may also be added, that by the addition of light jibs, secured to the timber uprights, the process of lifting the various parts may be readily accomplished.

BUILDING ROOF PRINCIPALS IN POSITION.

In the design just alluded to, it has been my object, not so much to give precise dimensions, as to convey a general idea of the apparatus; it will be apparent, however, on slight consideration, that the main timbers of the *traveller* must be placed wide enough asunder to give lateral stability to the *frame*. The outer wheels of the traveller are shown in the *Plate* somewhat too near the line of the centre of gravity of the frame but this is only a *detail* easily corrected in practice.

The *traveller* is represented as running upon gantries fixed parallel with the walls of the building, but it could obviously be fixed at its extremities upon trestles on wheels running upon rails laid at the level of the ground.

Roof of railway station, New Street, Birmingham.

Taking up the subject of roofs in chronological order, one of an early date, namely, a roof over the *Joint Railway Station*, New Street, Birmingham, formed the subject of an able paper by Mr. Joseph Phillips, read at the Institution of Civil Engineers, in January, 1855 (M.P.I.C.E.,Vol. xiv.).

In designing this roof, a point requiring much consideration had to be attended to, namely, that the form of the building tapered off from a span of 212 feet at one end, to 190 feet 9 inches at the other, while the chord lines of all the principals sprung at the same level, and the versed sines of both the tie-bars as well as the arches were in all cases equal, namely, of the former 20 and of the latter 40 feet. Thus the *ridge* was horizontal throughout. The manner of erecting the roof was very ingenious in design and successful in practice.

It was all the more difficult as the roof had to be erected without interference with the large railway traffic going on in the station.

A moveable stage, about 18 feet in width, was constructed, of the full width of the station, resting upon six strong trestles arranged at distances to suit the lines of railway, platforms, &c. The stage was carried over the spaces between the trestles, by means of deep trussed girders of timber, whose lower sides admitted of the passage of the traffic beneath them, while at top they supported the platform, nearly concentric with the curve of the tie-bar.

The arched member of each principal was divided into five pieces, each of which was hoisted into its place by five sheer-legs, *one* erected over the centre of each piece (seen transversely), and *all* over the centre line of the principal. The pieces were left swinging from the sheers until all were up to their proper height, when the ends were secured and riveted together. After this, the ties, struts, and other pieces were conveniently lifted by light tackles from the arch rib, and all secured in their places together.

Charing Cross railway station roof.

I now proceed to describe in reference to *Plates* X. *to* XII., the framework used for the erection of the roof of the Charing Cross Station, ably designed and carried out by Mr. Phillips. This framing may be described

ERECTING IRON ARCHED BRIDGES.

they can be adjusted by means of taper keys. By these means the skewbacks can be wedged up to any required degree of tightness against the end of the arched ribs, the circular shape of the extremities allowing of their settling into their permanent positions without strain on the outside portions of the skewbacks.

Even, however, if we admit that these circular joints will always remain perfect (which seems doubtful), the question may fairly be raised of how far it is an advantage, for, if there is any analogy between arch ribs and columns (as the lecturer believes there is) then it is an obvious disadvantage to substitute a circular end for a flat one.

RAISING ROOF PRINCIPALS INTO PLACE.

When roofs of about 30 to 40 feet span are to be erected, the principals previously put together on the ground, may be lifted entire into their places by a single stout pole, somewhat inclined from the perpendicular, and supported by guy ropes running at an angle, backwards to the pole, and down to the level of the ground.

As in this method the pulley tackle requires to be secured to the principal in process of lifting at its apex, all the strains which the principal has been designed to meet will be reversed, and accordingly, the tie-rod will require to be sufficiently stiffened to bear a compressive strain; this can be done conveniently by means of a pair of thin pieces of fir bolted together with the tie-bar between them. The single pole has in this application (as well as in the lifting of girders before described) the advantage of enabling us to pick up the principal when lying in a position sufficiently oblique to allow of passing up between the wall, and then of being slewed round and lowered into its proper position.

BUILDING ROOF PRINCIPALS IN POSITION.

The next class of roofs up to 50 feet and 60 feet span, I should propose to erect simply by the use of ordinary scaffold poles and planks, as follows:—say for a 50 feet span.

For lifting the 1st principal, to erect two lines of scaffold poles, in a direction traverse to the length of the building, four poles in each line, the lines of poles to be the same distance asunder as that of the principals, but placed about a couple of feet on one side of them. The poles next the walls to be about 3 feet distant from them, and the other spaced at nearly equal distances; to these upright poles would be attached eight horizontal ones of about 4 feet greater length than the spaces between the principals. These would serve to support the principal rafters and tie-bar while yet disconnected, and would afford the means of readily scaffolding up to the various points required for connecting the struts and ties. After a couple of the principals had been erected, one line of the upright scaffold poles would be entirely dispensed with, as, for erecting the *third*, and all subsequent principals, one end of the horizontal poles would be lashed to the last finished principal, while their other ends would be lashed to the upright poles. The economy of this method would be considerable, as few things are cheaper than scaffold poles of moderate length, they are easily handled, are very strong, and require quite a minimum of skilled labour to erect.

In roofs of greater span than the foregoing, up to 70 and 80 feet, and particularly when the building is long enough to justify it, I have designed an apparatus for their erection, which I am of opinion would be both quick as well as economical (*Plate* IX.).

This plan may be described in general terms as consisting of a vertical frame of timber of an outside figure somewhat similar to the principals to be erected; this frame is mounted upon a traveller capable of running

BUILDING ROOF PRINCIPALS IN POSITION.

from end to end of the building, and so to apply itself seriatim to each principal in its turn. The frame is contrived to allow of the principal being lodged upon it at a distance of about 1 foot from its hinder vertical face, the tie-bar being supported on chocks on the upper side of the traveller, while the principal rafters are placed upon projecting angle-iron brackets bolted to the upright timbers of the frame. Thus supported, with convenience afforded for plank scaffolding, the attachment of the struts and braces becomes simple and easy. It may also be added, that by the addition of light jibs, secured to the timber uprights, the process of lifting the various parts may be readily accomplished.

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Charing Cross railway station roof.

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BUILDING ROOF PRINCIPALS IN POSITION.

Charing Cross railway station roof.

in general terms as consisting of three main trestles or assemblages of timber, of an outside width (transverse to the line of railway) to the centres of the timber uprights, of 146 feet, or 18 feet less than the width of the station within the walls. Two of the trestles are loftier than the third one, as their upper parts reach to about 1 foot 6 inches below the extreme summit of the arched portion of the principal to be fixed, at which level they are finished off by timbers continued at each end, 10 feet 6 inches beyond the outside uprights, making them 167 feet over all. The third, or lower trestle is 20 feet lower at the centre than the other two and is finished at top in a curved form running nearly parallel with the bottom, or tie-bar of the principal, at a minimum distance of about 2 feet beneath it. Viewed transversely, *i.e.*, in the direction of the length of the station, the two latter trestles are placed at a distance of 18 feet from centre to centre, and the lower one at a distance of 22 feet (centre and centre of uprights) from the last of the two former ones.

The longitudinal timbers on the tops of the taller trestles are furnished with rails, serving for the passage of a travelling lorrie, carrying a light crane jib, right across from one side to the other of the station. At the level of the top of the lower trestle, and corresponding to its curved form, a planked platform is constructed, its breadth extending over the 22 feet span between the lower and first upper trestle, and sailing over 2 feet 6 inches at each side, giving 27 feet for its total width. It is upon this platform that the curved tie-bar is put together and laid in line, at a distance of 2 feet 6 inches from the centre of the first taller trestle. The upper member of the principal is put together and supported perpendicular over the tie-bar, upon the ends of timbers extending across the 18 feet between the two tall trestles, and at one end projecting 3 feet beyond. All this being done, namely, the upper arched member, resting at its extremities upon the walls, and the tie-bar upon its platform, the fixing of the vertical and diagonal members of the principal becomes very simple and easy. The purlins and various pieces occurring between the principal just completed and the last one being fixed, the whole system of these trestles is moved upon its wheels to the situation for the next principal. The convenience of the arrangement for supporting the arched part of the principal, here shewn as being carried on the ends of the transverse timbers projecting beyond the uprights, is that the framework can be readily drawn away from it. The platform for supporting the tie-bar can also be withdrawn with equal ease from beneath it. It will be seen that there is an opening of 35 feet by 5 feet left in the curved platform to allow of the hoisting up of the component parts of the principal by means of the short crane jib projecting from the side of the traveller.

In the elevational view of the framework, it will be observed to consist of five main upright timbers 12 inches by 12 inches, placed symmetrically, one in the middle, the next pair at distances of 37 feet 6 inches on each side of the middle one, and the next pair 35 feet from the former, all measured from the centres of the timbers.

Beneath the horizontal timbers (10 inches by 10 inches), for carrying the travelling lorrie, the uprights are 85 feet in height above the level of the rails in the station, while at heights of 26 feet, 46 feet, and 82 feet (above the same level) the uprights are kept in place by double walings (each 10 inches by 5 inches), one on each side of the uprights; all excepting the upper pair (which are discontinuous for a width of 34 feet

BUILDING ROOF PRINCIPALS IN POSITION.

across the centre of the framing) extending about a foot at each end beyond the extreme outside width of the framing.

Charing Cross railway station roof.

Up to the level of the first set of walings, the uprights (in the elevational view), are left entirely without any diagonal bracing, it having been found that a certain amount of elasticity in them was favourable to the ease of moving the wheels of the framework on the rails beneath. Between the first and second tiers of walings, the bays between the uprights are each divided into equal parts by a pair of raking struts (10 inches by 5 inches), which, starting from the full width of each bay (on top of the first tier of walings), meet together beneath the second tier, and immediately over them, supporting a series of uprights (12 inches by 12 inches), the tops of which run up to the same altitude as the full length ones previously described.

The second tier of walings serves as a tie, forming the chord of the arc, of the pair of curved walings for supporting the curved tie-bar of the principal, between which two sets of walings, and across the bays formed by the uprights, diagonal timber struts, 10 inches by 5 inches, are thrown.

Each bay between the third set of walings and the top timbers for the travelling lorrie, is divided at top by inclined struts (5 inches by 5 inches), the full width of the bay asunder at bottom, and meeting together at top.

In the transverse view, each set of the three upright timbers are all secured together at bottom by a pair of walings (12 inches by 12 inches), one on each side of them, the space between allowing of the introduction of the travelling wheels or rollers (2 feet 6 inches diameter), one under each upright in each view, making 15 in all.

Other pairs of walings are also introduced in this view, one pair immediately beneath each tier in the elevational view. Cross bracing only exists in this view, in each of the spaces above the second tier of walings.

The total weight of timber, &c., in the above framework, comes out at about 110 tons, where the weight of one principal resting upon it would not exceed 40 tons, showing how large a proportion of the strain on the staging is due to its own weight.

It may also be added that the using of so large a mass of timber in such framings arises from the necessity of providing sufficient width at the base (when the roof is so elevated) to withstand, not merely the dead weight, but also the lateral action of the wind upon uncompleted portions of the roof.

Roof over Cannon Street station

The roof of Cannon Street Station, built subsequently to Charing Cross, is of larger dimensions than it, namely, the span between the walls 201 feet 8 inches, clear span of roof 190 feet 4½ inches, with height of tie-bar above springing of 30 feet, and height of arch rib above the tie-bar also 30 feet. The distance apart of principals 33 feet 6 inches, weight of each 47¼ tons.

The manner of erection was by means of a timber framework very generally similar to that for Charing Cross, efficiently carried out by Mr. Phillips.

Roof over St. Pancras station.

Proceeding now to St. Pancras Station, which is a building of about 706 feet by 240 feet within the walls: we have the principal of 240 feet clear span, springing from the level of the platforms, with a rise of 96 feet from the same level, placed at a distance of 29 feet 4 inches from centre to centre, and each weighing 55 tons.

In the erection of this roof, more than usual precautions had to be taken (in consequence of its enormous span and altitude) to guard

BUILDING ROOF PRINCIPALS IN POSITION.

Roof over St. Pancras station.

against the effects of the wind, laterally upon the ribs, tending to overset them before the wind braces (appliances running diagonally to, and secured to the walls) could be applied. We are thus prepared to find the timber framing for the erection of the roof to consist of a very large mass of timber, presenting a considerable length of base, laterally to the principals, and here (similarly to the Charing Cross framing) the proportion of weight of the framing, to the principal it has to carry is very small, namely—

	lbs.		tons.
Timber work, 26,000 cubic feet at	40	=	460
Iron work			80
Total ...			544

Thus we have the framing equal to 544 tons, to weight of one rib 55 tons; and even this weight of 55 tons is never actually bearing upon the framing, as, in the process of erection, each rib is commenced from two fixed points, one on each side of the station, from whence it is continued up to the top, the side supports, of course, bearing a large proportion of the weight.

The roof of the St. Pancras Station was erected in the year 1870, by the Butterley Iron Company, whose model of the timber framing (kindly lent me by their manager Sir John Alleyne) is now upon the table (*Plates* XIII. *and* XIV.).

The timber framing consists of three separate main assemblages, each assemblage moveable independently of the others, upon wheels running upon rails, longitudinally to the station, and at the level of the permanent rails of the line.

Beginning from the bottom, *the centre assemblage* rested upon 63 cast iron wheels of 24·6 inches diameter each, with axles of $3\frac{1}{4}$ inches diameter, running in bearings affixed to the half timbers above them. Viewed in the elevation, the central assemblage consists, first, of the timbers (12 inches by 6 inches), to which the bearings of the travelling wheels are attached, arranged in seven pairs, longitudinally with the station, each pair 40 feet in length, and arranged at distances of 11 feet 7 inches from centre to centre, with a space between them of 12 inches.

Upon the half timbers, and running transversely to the station, 5 lines of whole timber sills (12 inches by 12 inches) are placed, at distances of 8 feet 8 inches, 20 feet 8 inches, and 8 feet 8 inches asunder from centre to centre, each sill 73 feet in length, and on each timber (except the middle one) 7 whole timber uprights (12 inches by 12 inches) are erected at distances of 11 feet 7 inches from centre to centre, their lower ends being inserted in cast iron sockets.

Dividing the total height of the upright timbers into three equal parts, the first division above the sills being (as above) 12 inches by 12 inches, the next is 10 inches by 10 inches, and the top pieces 9 inches by 9 inches, and at each change of dimension the difference is allowed for by the introduction of cast iron socket pieces made to fit the timbers. At each of the above points, and also at points intermediate between them, double sills, each 12 inches by 6 inches, are attached, in both the transverse and longitudinal directions, one on each side, to the uprights. The whole framing is well and substantially braced by diagonal struts thrown in across the angles of the rectangular openings formed by the upright and

BUILDING ROOF PRINCIPALS IN POSITION.

Roof over St. Pancras railway station.

horizontal timbers, and well wedged up at top. Cross bracing, to prevent racking, is also applied, both in the horizontal as well as vertical planes, seen in the transverse view and plan of the framing.

All that is stated above, in reference to the front row of seven timber uprights of the central assemblage, seen in the elevation, equally applies to the three other rows behind it, placed at distances of 8 feet 8 inches, 20 feet 8 inches, and 8 feet 8 inches from centre to centre.

The *two side assemblages* of the framing are exactly similar to each other, and resemble the *central assemblage*, except that there are in them only six upright timbers (elevationally), instead of seven; that their heights gradually diminish, to suit the contour of the interior of the roof, and that there are only 30 travelling wheels in each side assemblage.

The width of the framing (*i.e.*, seen in plan or in the transverse direction), is so arranged as to sustain two main ribs of the roof at a distance of 29 feet 4 inches from centre to centre, which then fall perpendicularly over the middle of the 8 feet 8 inches span, above named.

We will now assume that the three assemblages of framing are to be prepared for the reception of the iron ribs, which is to be done by placing them accurately in line, bolting down the sills to the floor, and firmly wedging between the assemblages at the four points in the height, shown on the elevation.

The stages, shewn at eight different altitudes of the elevation, must now be referred to.

These are for the purpose of affixing the derrick jib shown for hoisting up the different sections of the rib, and for the convenience of the workmen engaged in riveting the sections together, &c., for which purpose they are arranged at suitable heights in relation to the joinings. They also serve as a support for the moveable pieces of timber termed *slides*, seen to project from them a little beyond the inner boundary of the arch rib. These *slides* have an important function to perform, for they serve at the same time to bear such part of the weight of the sections as comes upon them, as well as to clip the rib laterally, the use of which will presently be seen.

In consequence of the three assemblages of the frames being entirely disconnected, any one section is capable of being moved independently of the others, and accordingly, let us suppose I to be the position of a complete rib, relatively to the section of the framing A B C D. The slide clips in this section are then to remain firmly bolted up, while those in the section E F G H are released, allowing of its being moved forwards to the position shown, when its backward slide clips are to be tightened up upon the rib I, those upon the former section slackened, and the section itself moved forward in range with the other one, when the whole framework is ready for the reception of another rib, K.

The principal object of the above arrangement is to afford lateral support at all times to the ribs, which it will be perceived is accomplished by always keeping fast hold of the rib by one or more sections of the framing during the time the other one (or two) is released.

The process of lifting the sections of the ribs into place was done by means of hoisting jibs, or derricks, capable of being swung round; four of them were in constant use, two at each side of the stage. The head of each derrick is fitted with the usual swivel arrangement, and at the foot a ball and socket joint is formed to prevent the derrick being jerked off its pivot by any accident.

BUILDING ROOF PRINCIPALS IN POSITION

When in the act of hoisting the segments, the derricks had to project clear over the sides and ends of the staging, and when high enough, the segment was swung round to its proper place. When not in use, or when the staging was passing from the main rib last fixed to the next one, the guy rods were removed, and the derricks were lowered on to the platforms.

The derricks were all worked by ropes, which, after passing over snatch and fairlead blocks, were lead away to a steam crab fixed upon the floor of the station.

The steam crab was specially designed for this work by Messrs. Appleby Brothers. It has two barrels. Two permanent ropes can be wound on it at once; the ends of the shafts which carry the barrels are prolonged outside the framing, and carry a pair of warping barrels, both of which were worked in the same direction, and the rope wound half round each several times, by which system there is no surging of the rope, and it can be removed in a moment.

As before mentioned, all the ropes from the staging led to the steam crab, where they were thrown on and off, and coiled away in a perfectly satisfactory manner.

DIFFERENT MODES OF ERECTING BRIDGES.

In a Paper on *Different Modes of Erecting Bridges*, read at the Institution of Civil Engineers, by Mr. Theophilus Seyrig, M.I.C.E., in December, 1880, much valuable information was given, full details of which will be found in the "Minutes of the Proceedings of the Institution."

The following summary of the Paper has been condensed from the short report given in *The Building News* of the 10th December, 1880:—

1. *Erection upon Staging.*—The use of standards equally spaced was illustrated by descriptions of the timber stagings employed in the erection of the railway bridges over the Thoiss, at Allgyö in Hungary, with 328-ft. span; over the Erdre, at Nantes, in Brittany, with 321-ft. span, and over the Thaya, at Znaïm, in Moravia.

As examples of clustered standards the timber stagings were described of the Pont du Carrousel, Paris, with 157-ft. spans; Bordeaux bridge with 253-ft. span; the railway bridge over the Lek, at Kuilenburg in Holland, 429-ft. span; and Bommel bridge over the Waal, with 393-ft. spans.

A light iron platform suspended from chains was employed for erecting El Kantara bridge in Algeria, at a height of 393-ft., with 184-ft. span.

Light iron lattice girders supported on clusters of timber piles, were used for erecting the railway bridge over the river Inn, at Königswart, in Bavaria, with three spans of 227ft.; but the intermediate piles in the middle span having been swept away by a flood, a temporary wrought iron framework, stretching across the entire opening, was erected by over-hang, its panels advancing from the piers at each side and meeting midway.

DIFFERENT MODES OF ERECTING BRIDGES.

The danger incurred by staging constructed across rivers liable to floods and drift was exemplified by the disasters at Hamm railway bridge in Rhenish Prussia, crossing the Rhine with 340-ft. spans; by settlement of the staging at Kuilenburg bridge; and by the mishap at Köingswart bridge.

Rapidity of erection upon staging was illustrated by examples of bridges put together on the American system of pin connection, without riveting.

2. *Erection by lifting bodily*—Originated at the Brittania bridge in 1848. This plan was imitated at the Saltash bridge for the two large spans of 455ft.; and at the railway bridge over the Weser, near Bremen, in 1867. The railway bridge at Moerdyk in Holland, having fourteen openings of 328ft., had lately been erected in a similar way. At the Niagara bridge, spans of 197 ft. and 248 ft. were erected upon a floating staging, consisting of a platform carried on pontoons.

3. *Erection by Rolling Over.*—The facility of erection by rolling over led to its original adoption for the Sarine railway viaduct at Freiburg, in Switzerland, where the roadway was constructed on the hill, behind one of the abutments, and then, by means of windlasses, was pushed bodily forwards upon rollers across the successive openings of 160ft. between the piers. A similar method was carried out for Stadlau bridge at Vienna, crossing 232-ft. spans. At Waldshut bridge over the Rhine in Switzerland, the windlasses were replaced by ratchet-wheels keyed on the roller-spindles, and worked by levers, whereby the rollers were transformed into driving-rollers, and the use of hauling-ropes was dispensed with.

For the replacing of existing bridges by new work in a very speedy way, the new roadway had been erected alongside the old one, and had then been rolled into its place sideways. On railways in Hungary and Austria a number of timber spans, varying from 26ft. to 210ft. had been thus successfully replaced. A description was given of the operations at Hernad bridge on the Oderberg and Kaschau line, where two 82-ft. spans were thus renewed with only about four hours interruption of traffic.

In the renewal of one of the Prater bridges on the Austrian State Railway, near Vienna, the new bridge of 350 tons weight, constructed of bowstring girders of 200-ft. span, and carrying two lines of way, was rolled into position by a live set of old cannon-balls, instead of upon rollers; the same device had previously been used in renewing a single-line bridge over the Waag, at Tornocz. Rolling had also been applied to the temporary timber staging employed for the erection of the permanent structure.

This method was illustrated by the successful erection of St. Just-road bridge, over the Ardèche in France, with 152-ft. clear openings spanned by arched wrought iron ribs. Another example was Regoa bridge over the Douro, in Portugal, with spans of 162-ft. and 263-ft.

4. *Erection by Building Out.*—The permanent structure being made use of for its own erection, dispensed altogether with extraneous appliances, hence, lifting bodily required less plant than staging, and building out still less.

El Cinca bridge, in Spain, the first erected by building out, had an arch of 230-ft. span, each half of which was erected as a cantaliver or wall-bracket projecting from the abutments until their ends met midway.

DIFFERENT MODES OF ERECTING BRIDGES.

At the steel bridge over the Mississippi at St. Louis, with two side arches of 502-ft. span, and a central one of 520-ft., the half-arches were erected from the masonry piers, proceeding on both sides of the piers simultaneously, so that the lateral strains should counterbalance one another.

The most recent example of erection by building out was the railway bridge crossing the Duoro, near Oporto, with a crescent-shaped arch of 525-ft. span, the height of the extrados at the crown being 200ft. above the water. The abutments and the iron piers on each bank having been first erected, and the continuous roadway girders having been pushed across them far enough to overhang the arch 105ft. at each side, the arch itself was then erected, panel by panel, from the springing, the overhanging panels being successively supported by wire ropes, tying their outer extremities to the horizontal girder over-head, where it rested on the pier. The principal details connected with the erection of this bridge were described at length, as an example of work carried to a completely successful issue under conditions ensuring great safety.

PLATE. I.

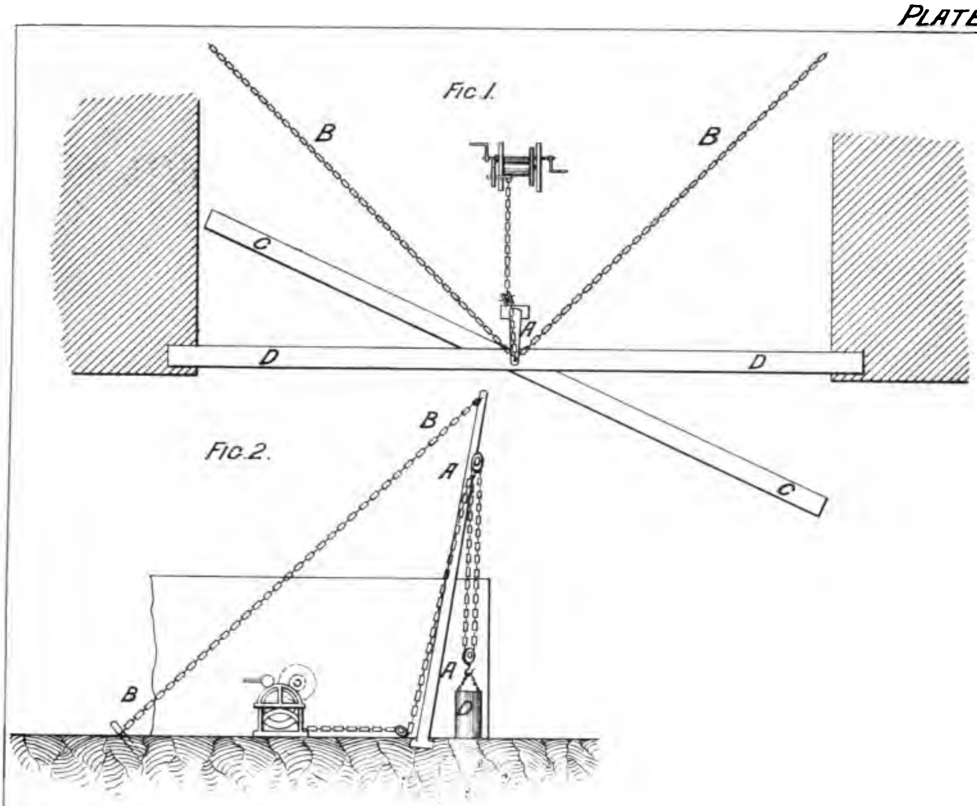


FIG. 1.

FIG. 2.

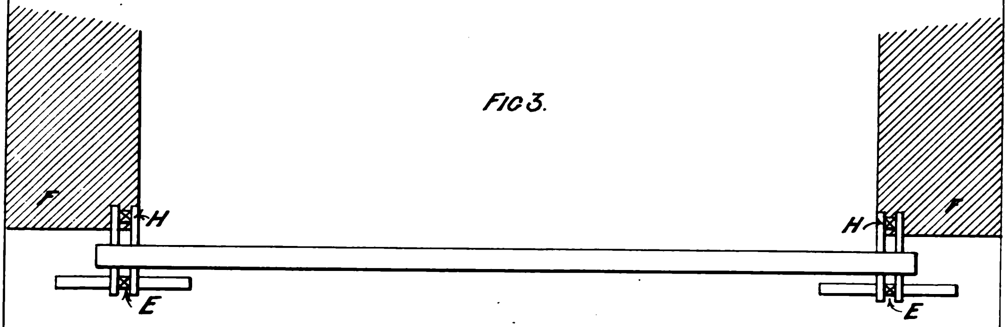


FIG. 3.

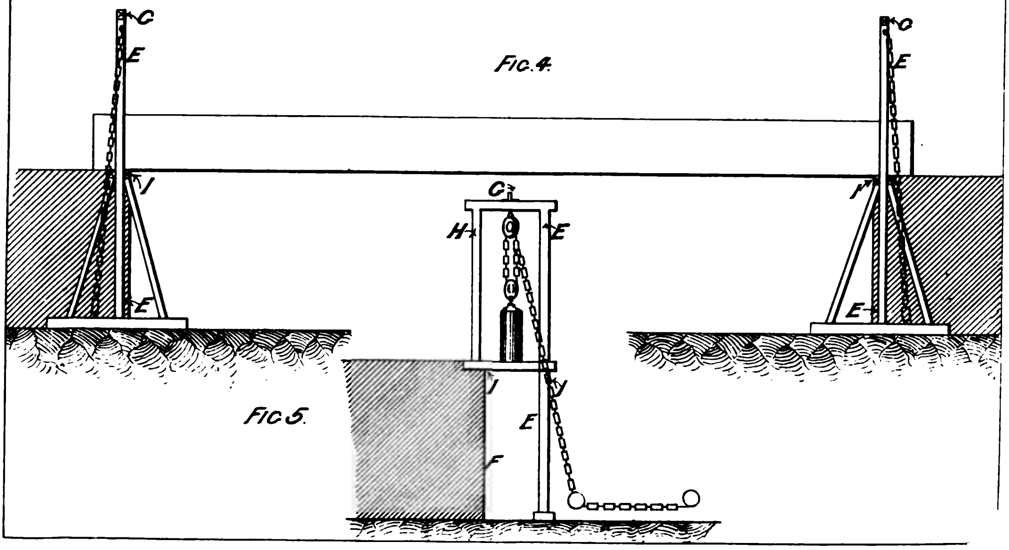


FIG. 4.

FIG. 5.

PLATE 2.

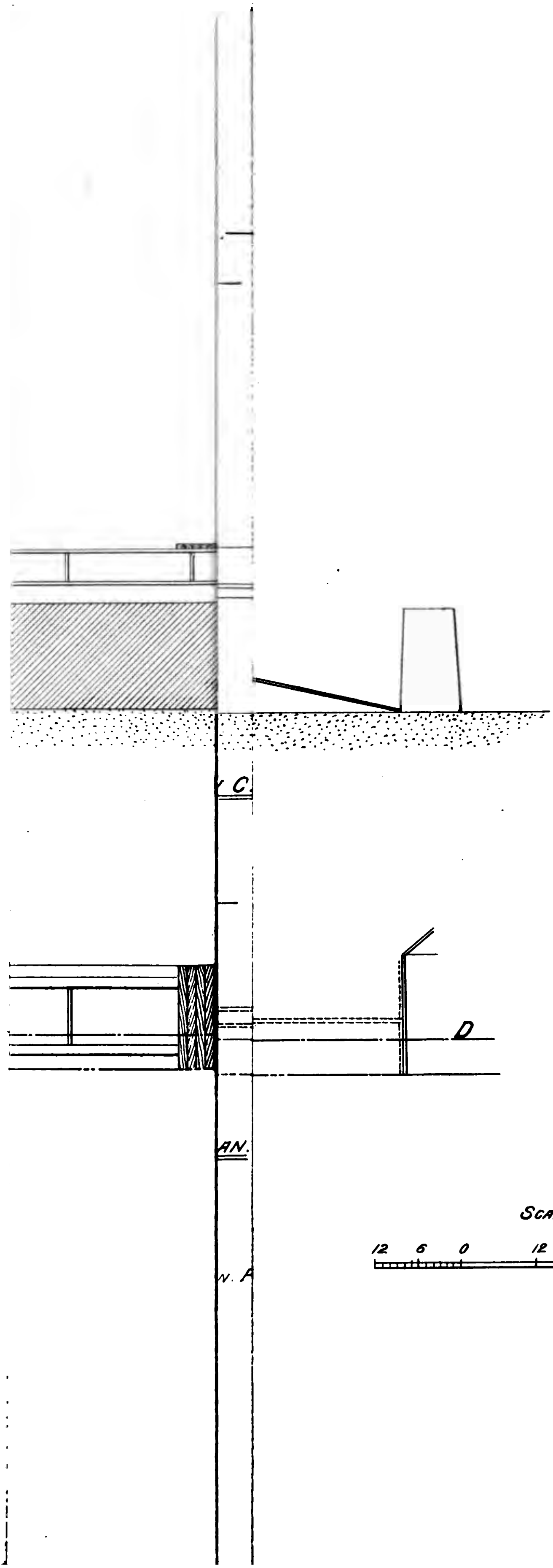
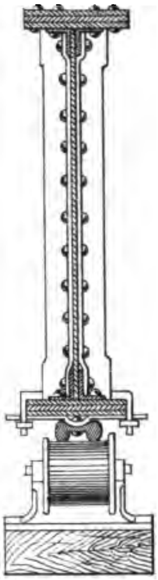


FIG. 3.



SCALE FOR FIG. 3.

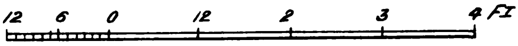


PLATE. 3

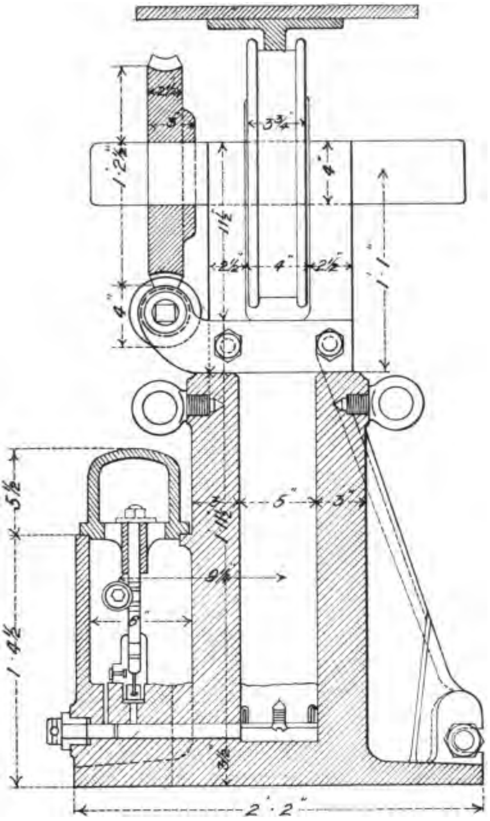


FIG. 1.

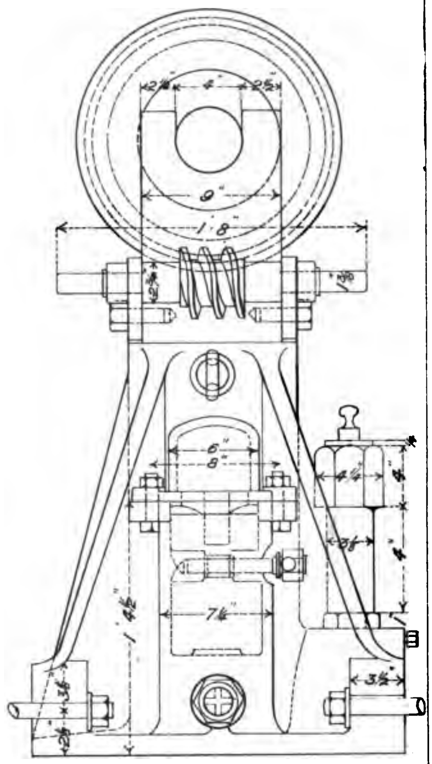


FIG. 2.

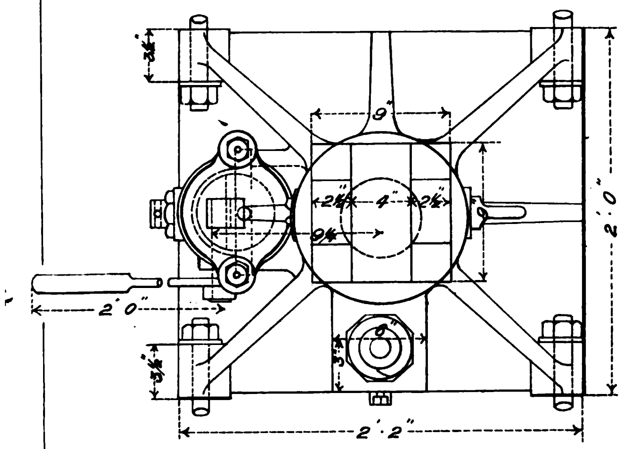
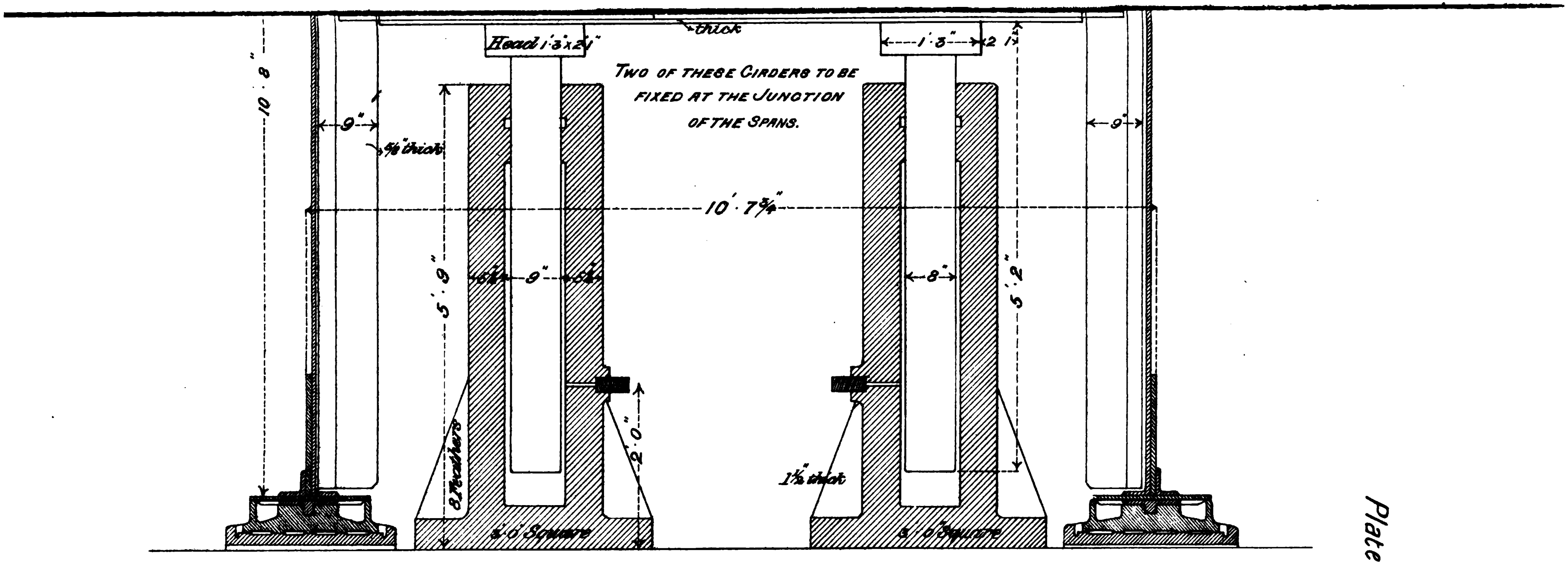
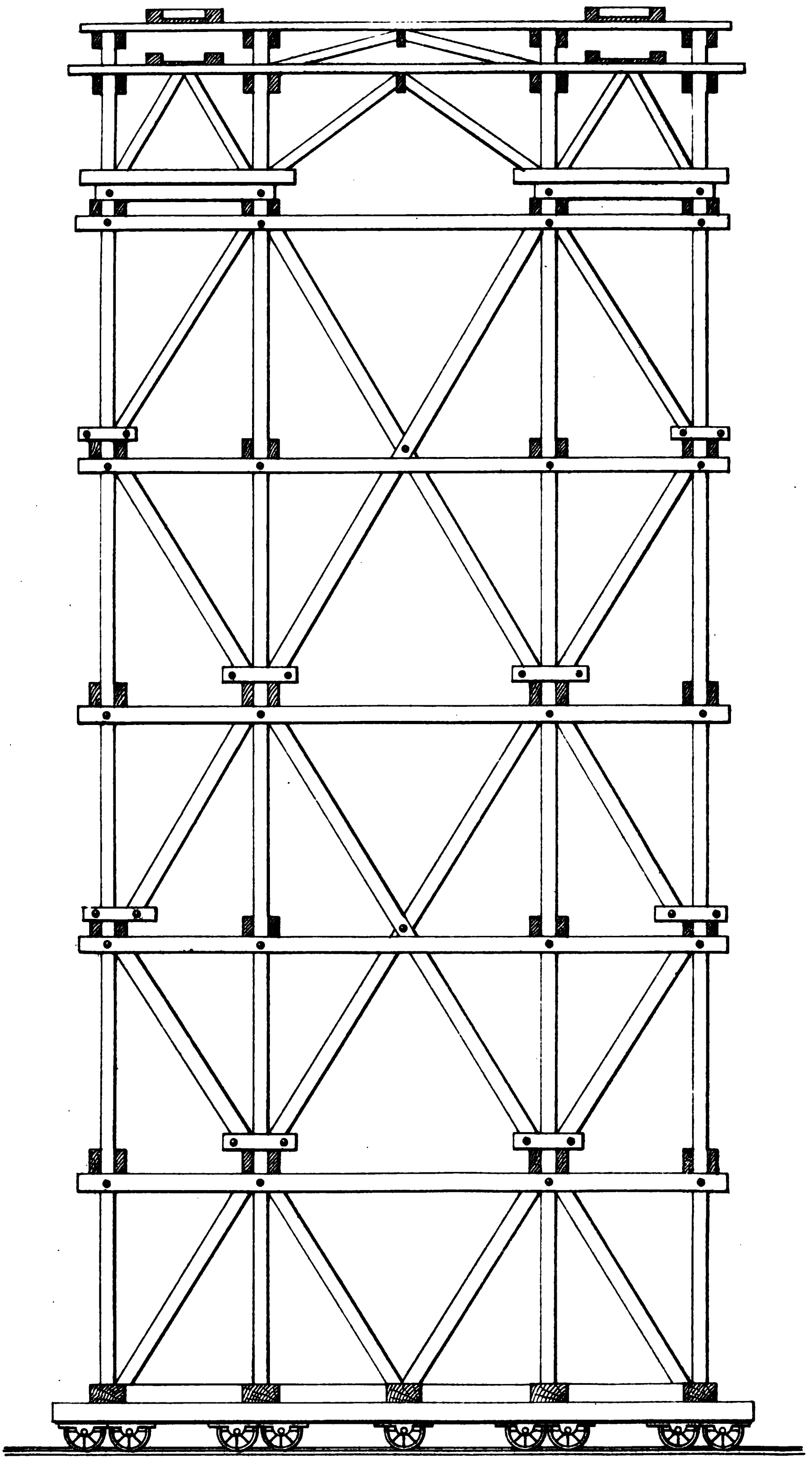


FIG. 3.

Plate 4.



TWO OF THESE GIRDERS TO BE FIXED AT THE JUNCTION OF THE SPANS.



SAINT PANCRAS.

CROSS SECTION OF CENTRAL PART OF SCAFFOLDING.

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